TREATMENT AND POST-TREATMENT POSTERIOR OCCLUSAL CHANGES IN INVISALIGN® AND TRADITIONAL BRACES: A RANDOMIZED CONTROLLED TRIAL

A Thesis

by

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ABSTRACT

Invisalign® and traditional braces are two treatment modalities available for patients seeking orthodontic improvement. The purpose of the present study was to compare treatment and post-treatment posterior occlusal changes in adult subjects with Class I malocclusion treated with Invisalign® or traditional braces. The study's retention protocol was upper wraparound Hawley with bonded lower 3-3 retainer. Blu Mousse® bite registrations and orthodontic study models were collected at pre-treatment (T1), debond (T2), 1 month into retention (T3), and 6 months into retention (T4). Areas of contact and near contact (ACNC) were evaluated at 0-350 microns, as well as marginal ridge and buccolingual inclination scores from the American Board of Orthodontics' Cast-Radiograph Evaluation (ABO CRE). Orthodontic treatment decreased ACNC in both treatment groups significantly ($p<0.05$); ACNC decreased between 54-75% during treatment. The most significant ACNC increase occurred between T2-T3 in both groups, between 25-94%. Though settling continued, there was no significant change in either group between T3-T4. Neither group achieved pre-treatment ACNC values by six months of retention. Likewise, no significant changes in mean marginal ridges nor buccolingual inclination scores occurred in either group over the course of the study. According to longitudinal analyses, there were no significant between-group differences at any timepoint, indicating that Invisalign® and traditional braces can have similar treatment results as well as settle similarly during six months of retention. It could be of benefit to the patient to consider equilibration during the retention phase to alleviate interferences that inhibit further settling and improvement in ACNC.

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CHAPTER I
INTRODUCTION

With more adult patients seeking orthodontic treatment, esthetic options, such as clear or tooth-colored technologies, are in higher demand. The most well-known clear aligner therapy (CAT) is Invisalign® (Align Technology, San Jose CA). It offers patients removable, clear alternatives to traditional fixed metal braces. However, treatment time with Invisalign® compared to traditional braces appears to be variable[1,2] and limitations of the technology exist[3,4]. Side effects of CAT can occur, such as posterior open bite at the end of treatment due to the interocclusal thickness of plastic.[5] However, the literature lacks definitive information evaluating posterior occlusal changes during retention of patients treated with plastic trays.

A common method dentists use to evaluate posterior occlusion is articulating paper. However, this is a subjective method that depends on the ability of the paper to accurately mark the teeth.[6] Marking ability varied between colors and brands of articulating paper, with intraclass correlations of 0.74 and 0.76 for the first and second molars. These correlations are fairly weak, considering different papers are supposed to be marking the same contacts.[6] Orthodontists commonly assess posterior occlusion by counting occlusal contacts and measuring buccolingual inclinations and marginal ridge discrepancies with the American Board of Orthodontics Cast-Radiograph Evaluation (ABO CRE). Though several studies have utilized this method to evaluate posterior occlusion[2-4], the assessments are also relatively subjective, which decreases reliability. Another method is using bite registrations, such as Blu-Mousse®, to record posterior occlusion.[7-11] Transillumination allows visualization of areas of contact and near contact (ACNC), which allows counting the number of contacts[12,13] or evaluating the areas of contact and near contact in square millimeters[7-11]. This latter technique is more objective than visually counting contacts. The use of a step wedge as a calibration tool to evaluate in square millimeters the area of contact and near contact has also been performed.[7-11]

A goal of orthodontic treatment is to give patients a functional bite. In order to function optimally, the number of posterior occlusal contacts is critical. Ricketts recommends 16-24 contacts per side.[14] According to Bakke et al, occlusal contacts are important because they determine occlusal stability and are closely related to bite force.[15] Masticatory efficiency is also dependent on contacts and near contacts.[7,8] Both braces and Invisalign® treatment tend to decrease contacts. Sullivan et al found a decrease of nearly 50% in the number of contacts post-treatment in subjects treated with fixed appliances.[16] Invisalign® was found to have fewer posterior occlusal contacts measured using the American Board of Orthodontics Objective Grading System (ABO OGS) compared to traditional braces.[2,4]

After debond, the greatest rate of settling typically occurs within the first two months, with non-statistically significant changes after six months.[9] Based on the cone-funnel concept introduced by Van der Linden, the cusp-fossa relationship aids in development of proper intercuspation.[17] This settling occurs due to teeth moving independently to achieve an equilibrium with the opposing arch. However, even though posterior contacts may increase during retention, the numbers and locations may not improve to equal posterior contacts of untreated individuals.[16,18,19]

The goal of this randomized controlled trial is to compare the treatment and post-treatment changes in posterior occlusion of patients with Class I malocclusion treated with Invisalign® or traditional orthodontic braces. This study is necessary because no studies are available using the objective technique of transillumination to compare ACNC of the treatment modalities. Information regarding posterior occlusal changes of these patients during retention is lacking as well. Previous studies evaluating these treatment modalities are retrospective[3,4] or non-randomized cohorts[20], and therefore do not provide evidence from randomized controlled trials comparing treatment of adults with non-extraction Class I malocclusion.

CHAPTER II
LITERATURE REVIEW

The purpose of the proposed study is to investigate posterior occlusal changes in adults with Class I malocclusion treated with Invisalign® or traditional braces. Both the changes that occur during treatment and, more importantly, those that occur over the first 6 months of retention will be evaluated. To fully appreciate why these aims are important, it is imperative to become familiar with the background information already published. Unlike anterior occlusion, which has been extensively studied, posterior occlusion has not been thoroughly evaluated and remains poorly understood. However, it is of fundamental importance in terms of function and stability.

Part 1 will evaluate untreated individuals. First, the literature review will discuss the fundamental methods used to evaluate occlusion. Though several methods have been used to study posterior occlusion, not all are adequate or sensitive enough to detect changes. The differences will be highlighted in order to determine the most effective methods of assessment. Next, development and aging of the posterior dentition will be evaluated, as well as the resulting dental compensations that occur to maintain an equilibrium. In this section, interdigitation and cusp-fossa relationships will be introduced to provide information regarding the importance of the posterior dentition for proper guidance of development of the orofacial complex. It is critical to understand how the posterior occlusion responds to natural age-related changes because it can affect our choice of retention for treated individuals, as well as help us understand what can happen regardless of orthodontic treatment. Next, is there only one strict definition of an "ideal" occlusion, or is there a range of normal? This section will review philosophies surrounding normal posterior occlusion and how, despite existing in a dynamic environment, the dentition adapts to maintain its function. Following this discussion, the linear relationship of occlusion and malocclusion with bite force, occlusal contacts, and masticatory performance will be reviewed. This will elucidate how critical it is to possess a full, healthy dentition in the proper maxillomandibular orientation in order to achieve the most effective and efficient function. Lastly, what can change or affect contacts? An understanding of the contributing factors, such as diurnal effects, is imperative for evaluating any study of occlusion.

Part 2 will focus on treated individuals. It will begin by outlining various treatment options for those seeking orthodontic correction. However, it is imperative to consider proper case selection for patients wanting clear aligner therapy, and this will also be discussed. Next, treatment outcomes with emphasis on posterior occlusion of those treated with clear aligner therapy (CAT) versus those treated with traditional braces will be evaluated. Comparing Invisalign® with traditional braces is of paramount importance because it helps the clinician choose the most appropriate treatment modality for the patient. This evaluation will aid in the understanding of why the occlusion can differ in each group at the end of treatment. A discussion of retention will follow. This can be one of the most confusing aspects of providing a good treatment as there is no guarantee for lifelong stability unless lifelong retention is employed. First, the biological aspects of post-treatment changes will be reviewed, namely changes due to natural aging, relapse, and settling. It can be difficult to distinguish changes over time to relapse or the natural aging process, as they can be synergistic at times. Though it is critical to select a retainer to prevent relapse, it must also allow for some degree of settling to augment posterior interdigitation. Therefore, posterior occlusal changes will be discussed in regards to selecting the best retainer type to achieve the most settling in retention.

Part 1: Untreated Individuals

Occlusion is critical to many basic and higher functions we employ every day. From the function of eating and speaking to esthetics and social interaction, the maintenance of a proper occlusion is fundamentally important. An adequate occlusion has even been linked to improved cognitive function.[21] Orthodontics seeks to establish a visually appealing as well as functional bite to serve patients for their lifetime.

Occlusion can be divided into anterior and posterior portions. Anterior occlusion involves the upper and lower centrals, laterals, and canines, and should have light contact. Many studies have focused on mandibular anterior changes that occur post-treatment, as these are the most noticeable changes that occur. It can be difficult to distinguish between normal age-related changes and changes related to orthodontic relapse, as changes occur in both untreated and treated occlusions over time. The most frequent finding is that arch length decreases over time.[22-26] This occurs in all patients, as well as untreated individuals.[26,27] Therefore, one can extrapolate that decreased arch length affects both the anterior and posterior dentitions.

Posterior occlusion bears heavier contacts down the long axes of the dentition, which is composed of premolars and molars.[28] Anterior occlusion has been more extensively studied over the long-term than has posterior occlusion. However, posterior occlusion is key to maintaining proper function over the lifetime of the individual. In the following section, occlusion will be reviewed in the untreated individual.

Occlusal Evaluation

Methods of Assessing Occlusion

There are methods of evaluating the anterior dentition, such as Little's Irregularity Index and certain components of the ABO OGS (American Board of Orthodontics Objective Grading System), such as anterior alignment and overjet. Articles focus on changes in the anterior dentition because they are the most readily noticeable by the patient, both in terms of orthodontic relapse and natural aging.

Posterior occlusion is typically assessed in maximum intercuspation (MIP). According to Razdolsky et al, occlusal contacts in maximum intercuspation are repeatable with minimal error, and in their study, no significant differences were observed between two consecutive bite registrations.[29] In that study, polyether rubber impression material was used for bite registration; however, Blu Mousse® has been well-documented and used in many studies as a bite registration recording medium.[7-11] Likewise, the study by Sauget et al utilized Regisil® PB™, which is a vinyl polysiloxane similar to Blu Mousse®, and they found after repeated occlusal registrations in MIP that it was a very reproducible method of bite registration in maximum intercuspation, and they also noted that it has been validated in several other investigations.[13] Other studies, such as one by Garrido García et al, concluded that there is more variation between patients than there is within a patient in terms of comparing multiple consecutive bite registrations.[30] While in MIP, posterior occlusion can also be evaluated by various measurements of the ABO OGS, as well as the number or area of absolute contacts and near contacts (ACNC), as well as Angle classification.

The most fundamental assessment of posterior occlusion warrants a review of Angle classification. This is determined based on the position of the mesial buccal cusp of the maxillary first molar in relation to the buccal groove of the mandibular first molar. A Class I relationship is where these two references line up. A Class II is when the maxillary first molar is positioned anteriorly to the mandibular first molar landmark, and Class III is the opposite configuration. Though this method does not evaluate contacts, it does provide information regarding the relationship of maxillary to mandibular posterior dentition.

By 1998, the ABO had carried out multiple revisions of its grading system to establish a reliable instrument for assessing case treatment success. The ABO OGS evaluates posterior occlusion based on alignment, marginal ridges, buccolingual inclination, occlusal relationship, occlusal contacts, interproximal contacts, and root angulation.[31] Several studies have used this method to evaluate posterior occlusion.[2-4,20,32-34] However, because this method utilizes visual inspection of handheld models to determine occlusal contact presence, it is not the most accurate way of evaluating contacts.

As for occlusal contacts, many studies do not actually explain how they define these. Previous studies[12,13] have counted numbers of perforations in bite registrations and determined these to be their measure of absolute contact, whereas other studies[7-11] have evaluated the occlusal table more in depth by acquiring the actual areas of absolute contact and near contact, typically in square millimeters. Though simple to visualize, contacts may not be the most reflective of occlusal function. Near contacts increase the area of contact during function because of tooth movement in the PDL, and then near contacts often become absolute contact during that time.[35] As such, measuring areas of contacts and near contacts (ACNC) perhaps is the most complete way of evaluating posterior occlusion, rather than solely contacts; likewise, it is a more objective and quantifiable method than counting contacts.

Technical Methods of Obtaining and Evaluating Occlusal Records

Articulating paper offers the advantage of marking directly on the occlusal surfaces the locations of contacts between opposing teeth. However, depending on the surface topography of the dentition as well as the thickness of the articulating paper, the contact recording can differ.[6] This makes articulating paper a crude method of assessing repeated recordings on occlusal contact and should be used only in situations that do not require more accuracy.

Bite registrations can be acquired in various ways, including the computerized T-scan and photo-occlusion, or traditional methods using impression materials, such as polyether or silicone. The T-scan method utilizes a sensor connected to a computer to evaluate force and timing of occlusal contacts when a patient bites down. Force and timing of contacts are displayed in color, and the occlusion can be visualized on the computer screen. Though the T-scan method has been claimed to be reliable[30], other authors[36] have found that this method lacks proper sensitivity and counts fewer contacts than actually exist. The photo-occlusion technique utilizes a bite wafer and polariscope to visualize the occlusion. It was shown to not be reproducible, though it is more reproducible than articulating paper.[37] Impression materials, such as polyether or silicone, have proven to be very reliable for evaluating occlusion.[13,29] In the Razdolsky et al study, polyether bite registrations were acquired in succession and compared for accuracy and reproducibility.[29] A paired t-test indicated that there was no significant difference in the mean contact number recorded by the bite registrations ($p < 0.05$). In the Sauget et al study, a vinyl polysiloxane material was used to record bite registrations.[13] They measured near contacts with a caliper to be 0.20 mm or less, and repeated measurements of near contacts on duplicate registrations to determine reliability and reproducibility. In this study, they determined the bite registration material to be reliable and reproducible. The error in that study was only 0.018 mm, which they deemed to be within their limit of error and therefore reliable. These impression materials are typically placed on the occlusal surfaces of the teeth and allowed to set while the patient is in occlusion. They can be evaluated by a visual count of perforations, measured at certain thicknesses, or analyzed by transillumination to determine the number of absolute contacts or thresholds of areas of absolute and near contact.

Transillumination of bite registrations is another method of evaluating areas of contact and near contact. A bite registration material is typically used and placed on a lightbox to view the gradations of light through varying thicknesses of registration material. Isolation of the occlusal table via a computer imaging software allows quantification of the areas of contact and near contact. This provides maximal information about the quality and changes of absolute and near contacts. Several studies have used transillumination to evaluate occlusal contacts and near contacts.[7-11]

The transillumination method of detecting varying thicknesses of bite registration material is evaluated when converted from color to grayscale. Grayscale is determined by how much light is transmitted through the material and therefore how thick the material is. Grayscale ranges from pure black (0 bytes) to pure white (255 bytes). A computer software program calculates grayscales and corresponding number of pixels. It can then be determined the sum pixel values based on how many exist at a particular grayscale value.

In order to evaluate the bite registrations for ACNC, a step wedge is used as a calibration tool to relate Blu Mousse® material thickness to grayscale. Typically, 50 micron increments are evaluated, as pixel density less than 50 microns are not detectably different.[38] A computer program allows conversion to assess ACNC by designating a certain thickness as a corresponding grayscale value. A more accurate step wedge is one that is spherical of known diameter, as was used in the Allen thesis.[11] This sphere makes it possible to use the equation of a circle (Equation 2) to determine the distance (x) from the circle's center to a specific Blu Mousse® thickness (y) at any point on a continuous curve along the edge of a circle.

Posterior Occlusion

Posterior occlusion is critical to the function and stability of the dentition. In fact, early posterior tooth loss can negatively impact development of the maxilla[39] and mandible[40], which was studied in both cases in Wistar rats. Having a full dentition even from early life, therefore, is critical to supporting healthy oral function over the lifetime of an individual.

The posterior dentition continues to adapt with growth changes over time. To appreciate the mechanical aspects of the posterior dentition, we first must examine natural aging and how the system attempts to maintain stability in a changing environment.

Development and Aging of the Posterior Dentition

For guidance of the developing posterior dentition, proper cusp-fossa interdigitation is a critical scaffold. Van der Linden described cusps funneling into the opposing fossae during eruption.[17] In a study performed by Ostyn et al, molar and canine cusps were reduced in macacas and the results were compared to untreated controls.[41] They found a widening of the maxillary arch in the experimental group and palatal tilting of upper molars in controls, suggesting that the mandibular cusps may restrict the maxillary teeth from expanding. However, the only statistically significant difference between experimental and control groups was increased width in the maxillary second primary molar region ($p<0.05$). The other transverse measurements showed non-significant increases that occurred faster in the experimental group as well. Another Ostyn study revealed that interdigitation in macacas was critical for proper anteroposterior and vertical development of the orofacial complex, and should interdigitation not be present, a Class III appearance may follow.[42] These observations support the importance of a cusp-fossa relationship for the development and guidance of the dentition.

What is the nature of posterior occlusion during the natural aging process? Wear of the occlusal table occurs through parafunction as well as diet and food intake over time. With attrition comes a compensatory eruption of the teeth to maintain opposing occlusal contact.[43] This can occur in the presence of attrition or freeway space. Even if attrition is slight, the molars continue to erupt roughly 0.07 mm per year in an attempt to fill the freeway space, which is typically about 2 mm at rest; therefore the lower facial height tends to increase with age[43,44], and can do so more than 5 mm.[44] Likewise, mesial migration of teeth occurs in treated and untreated individuals due to the orientation of mesially-directed forces on the posterior dentition.[45,46] There is limited information regarding age-related changes in ACNC. Assuming that wear and compensatory eruption occur, it can be extrapolated that absolute contact size increases with age.

Number, Location, and Symmetry of Posterior Occlusal Contacts

Is there a number or symmetry of contacts that ensures good posterior occlusion? The literature is controversial. There are varying recommendations for the ideal numbers of contacts for a good occlusion. According to Ricketts, ideal occlusion is composed of 16-24 contacts per side, not considering third molars.[14] In a study done by Korioth, absolute contacts were evaluated by perforations in bite registration material to assess posterior occlusal contacts of 45 male adult subjects with Class I normal occlusions who had not been previously treated.[12] The upper and lower first and second molars appeared to have the most contacts. Approximately half of the sample had 7-9 absolute contacts on the right versus 6-8 on the left molars, with the other subjects ranging from 1-3 contacts to 13-15 contacts per side. In other words, substantial differences exist in untreated Class I normal adults ($p<0.001$). Moreoever, these numbers indicate that in order to have a well-functioning Class I normal occlusion, it is not necessary to have the 16-24 contacts per side suggested by Ricketts. In normal occlusions, it is not uncommon to find varying numbers, locations, as well as asymmetry of contacts from one side to the other.[12]

Posterior Occlusion and the Relationship Between Malocclusion, Bite Force, Occlusal Contacts, and Masticatory Performance

Occlusion determines the possible bite force, which affects the number of occlusal contacts, which in turn determines masticatory performance. If malocclusion is present, all of these can be affected. Similarly, stability is affected by molar relationship.

In a longitudinal study of roughly 30 years, untreated subjects with Class I molar relationships maintained, whereas Class II and III relationships became more maloccluded over the course of observation.[47] These results support the importance of the stability and functional advantage of a good Class I relationship.

Although malocclusion affects bite force, open bites and crossbites affect bite force more substantially than does Angle malocclusion.[35] In terms of force distribution, the molars are the area for the highest achievable bite force in the dentition. Unilaterally recorded bite forces in this region can be between 300-600 Newtons in a healthy dentition; to put this in perspective, the anterior teeth have been reported to achieve only 40% of the force that the molars can.[35] It is important to have well-distributed contacts throughout the posterior dentition to provide stability and ensure stronger, more efficient force delivery from the elevator muscles of the jaw. Intentionally increased bite forces can increase the number of occlusal contacts present, though this can be difficult to entirely control in in-vivo studies. However, in many of the discussed studies, consistent instructions were given to each patient for bite registration and this was determined to be adequate.[7-10,13,29,30,48,49] Though the number of posterior teeth is important, the number of occlusal contacts is even more critical in determining bite force and function. If a bite force increases from 30% of maximum to 100%, the occlusal contact area increases two-fold.[35] Likewise, Bakke et al determined that among adults, occlusal contacts had the greatest correlation with bite force as compared with many other potential contributing factors, such as age, sex, height, and even jaw angle; 10-20% of the variation in bite force can be accounted for by number of occlusal contacts.[15] With contacts recorded on the maxillary dentition, light bite force (20% of maximum bite force) exhibited fewer contacts overall than heavier forces (50% of maximum bite force) in both young adults ($p<0.01$) and adults ($p<0.001$), according to Riise at al.[50] Likewise, Ikebe et al also confirmed that in addition to other factors, bite force reduction can inhibit masticatory performance.[51] This may be explained by micromotion of teeth during function and compressibility of the periodontal ligament.

Those having normal occlusion demonstrate more contacts than subjects with Class I, II, or III malocclusion, and therefore have larger areas of contact and near contact.[8] It is important to keep this in mind when considering the negative impact of malocclusion on masticatory performance[52], and this is primarily due ACNC[7,8]. In the Lepley study, in addition to acquiring CutterSil® samples from 30 Class I occlusion subjects to study masticatory efficiency, Blu Mousse® bite registrations were acquired to measure ACNC and alginate impressions were obtained for study models.[7] At 50 micron intervals, ACNC was evaluated. ACNC was negatively correlated with mean particle size of the CutterSil® samples, indicating improved masticatory efficiency with those subjects having a higher value for ACNC. Likewise, though the areas of contact (0-50 microns) were larger than any of the other 50 micron intervals of near contact for both males and females, the total near contact area between 51-250 microns was larger than the contact areas themselves. Therefore, though the absolute contacts were 23.8 mm^2 for men and 23.4 mm^2 for women, total near contacts up to 250 microns were 44.9 mm^2 for men and 50.3 mm^2 for women. In the Owens et al study, the second molars were not included in the occlusal table analysis due to the fact that they were not erupted in all patients.[8] In this study, it was found that regardless of normal or malocclusion, absolute contacts (≤50 microns) were about 2 mm^2. Near contacts were more numerous than contacts for normal and malocclusion classes, though significantly more in the normal occlusion group at almost 40 mm^2 at 350 micron thickness; Class I malocclusion demonstrated greater near contact area than the other malocclusion classes. Likewise, the particle size was smaller for those with normal occlusions compared to malocclusions of any type studied, indicating that particle size is related to ACNC and a better ability to chew. With near contacts becoming contacts with increasing bite force, food can be crushed more effectively. This indicates that near contacts may be more important than actual contacts in terms of masticatory efficiency.

In agreement with the aforementioned studies, masticatory performance was positively correlated with the number of occluding contacts, with contacts being more important than number of teeth according to Helkimo et al.[53] According to Ikebe et al, a reduction in number of teeth can inhibit masticatory performance, whereas aging itself is not necessarily a factor.[51] Buschang also illustrates the importance of occlusal factors in efficiency.[54]

Diurnal Effects on Occlusal Contacts

Can time of day affect occlusal contact reportings? Research has confirmed that the answer to this question is yes. It has been reported that occlusal contacts can vary with time of day and that diurnal variations can occur. However, in the Berry et al study, neither the significance nor extent of the findings was investigated.[55] A follow-up study by Molligoda et al investigated the quantitative nature of these diurnal changes in contact variation and determined that there were changes between morning and night, but these changes were random, and they report that statistical tests confirm this.[56] A study by Proffit et al may offer a possible explanation for these seemingly random variations in contacts.[57] In this study, it was found that eruption of premolars varies throughout the day and night, as well as varied from day to day, primarily due to function. Therefore, one can extrapolate that the changes in contacts seen in these previously mentioned studies occurs due to varied function during the day and night.

Part 2: Treated Individuals

The following section evaluates treated patients. It will begin by discussing orthodontic treatment systems, focusing on Invisalign® and traditional fixed braces. This will evaluate the differences in treatment outcomes, although long-term comparisons are lacking. The biological contributors of orthodontic relapse, settling, and normal physiologic aging of the dentition will then be reviewed to demonstrate the importance of long-term retention protocols. Next, assessing degrees of settling among different retainer types is imperative to help clinicians evaluate how to anticipate posterior changes during retention.

Orthodontic Treatment Options and Clear Aligner Case Selection

Many options await patients for the correction of their occlusion concerns, including surgical, traditional fixed orthodontics, or removable clear aligner therapy. All have their indications and contraindications, and research has elucidated the advantages and disadvantages of each system. Traditional fixed orthodontics has evolved from metal bands secured to all teeth to small bonded metal or ceramic brackets. Braces offer control for a wide range of desired movements. Lingual orthodontics is another fixed appliance that offers greater concealment of treatment than do traditional facial metal brackets.

With the advent of clear aligners, many patients are moving toward more esthetic alternatives to traditional braces. Treatment of rotations without the use of braces was first discussed in 1946 by Kesling[58], and today clear aligner therapy has grown from his ideas. In 1997, Align Technology modernized clear aligners and today we use these as a possible treatment option for many patients.

Careful case selection is imperative, as crowding greater than about 5 mm, anterior-posterior discrepancies greater than 2 mm, tooth rotations greater than 20 degrees, open bites, teeth requiring greater than mild extrusion, and short clinical crowns are generally not recommended with clear aligner therapy.[59] Likewise, other movements such as anterior intrusion may be more readily performed than anterior extrusion, and rotations on rounded teeth may be more difficult to correct when using clear aligners.[60] However, many studies evaluating the ability of clear aligners to control tooth movement during treatment lack proper methodology and may be biased.[60] Much of the success or failure of the use of the technology is based on the clinician's clinical judgment and experience in case selection as recommendations vary.[61]

Treatment efficiency may also be a component of case selection. However, treatment time is variable when comparing whether clear aligner therapy or traditional braces is more efficient. In a study done by Buschang et al on Class I non-extraction cases, conventional edgewise braces involved a statistically significant increase in appointments, roughly 4, as compared to clear aligner therapy ($p<0.001$), as well as increased treatment time of about 5.5 months.[1] The increased treatment time was probably due to a detailing phase of braces, whereas the clear aligner therapy patients may not have received this phase. However, in a study by Li et al on premolar extraction cases, treatment time was about 44% longer with Invisalign® than with conventional orthodontics.[2]

Invisalign® and Traditional Braces: Treatment Outcome Evaluation

It is generally accepted that posterior occlusal contacts are reduced immediately post-treatment in cases treated with clear aligner therapy.[2,4,5] The literature also suggests a lower ABO passing rate observed with Invisalign®.[3,4] Most outcome studies utilize the ABO grading system. However, there are limitations of the ABO assessment, particularly in the case of measuring occlusal contacts. This is because the grader visually assesses presence of contact or no contact, rather than confirming it with articulating paper or bite registrations. Therefore, this is not an exact method of determining number or area of contact, nor measuring changes over time.

Several studies have assessed only Invisalign®.[3,59,61] In evaluating quality of treatment results with Invisalign®, Kassas et al assessed 31 complete sets of pre- and post-treatment Invisalign® records using the ABO Model Grading System (MGS).[3] It was determined that though tooth alignment ($p<0.001$) was improved with Invisalign®, clear aligners had no statistically significant effect on posterior occlusal contacts ($p=0.125$), marginal ridges ($p=0.107$) nor occlusal relationships ($p=0.124$). In this article, it was not indicated exactly when final records were taken after treatment, which may impact the amount of settling that occurred since the official end of treatment and therefore the occlusal contacts. It should also be mentioned that of the 31 Invisalign® cases studied, only 1 of these cases received a passing score using the ABO criteria. A study by Vlaskalic and Boyd discussed a variable posterior open bite in some patients as a side effect of clear aligners of different materials and thicknesses.[5] However, the specifics of when data was collected to evaluate the open bite was not provided.

Several studies have utilized the ABO grading criteria to compare treatment outcomes of Invisalign® with traditional braces (Table 1).[2,4] Djeu et al retrospectively evaluated 2 groups of 48 patients each: one group treated with Invisalign® and the other with traditional braces.[4] According to this study, scores for Invisalign® cases were higher than braces scores for occlusal contacts ($p=0.0004$) and occlusal relationship (p=0.0149). One of the stronger aspects of this study is that no time was allowed for settling post-treatment when final records were collected. This provides a clearer picture of post-treatment outcomes immediately after treatment, leaving no time for settling of the posterior occlusion nor improvement of the occlusal contact relationships. And, there also was determined to be a statistically significant difference between the ABO passing rates of Invisalign® and braces patients, with results favoring those treated with braces for the aforementioned reasons.

In contrast to the notion that traditional braces have a superior ABO passing rate than Invisalign®, a randomized study by Li et al reached a different conclusion.[2] Extraction treatment results were compared with Invisalign® versus conventional braces and determined that though numerically there was a greater rate of passing of the braces group in accordance with ABO grading standards, there was no statistical difference between this group and the Invisalign® group in terms of treatment outcome measured by the ABO criteria (p=0.52). However, their results agreed with Djeu et al[4] in regards to worse occlusal contacts in the Invisalign® group, measured by mean ABO OGS points lost (p=<0.001). The time at which T2 post-treatment records were acquired was not specified.

Lastly, an explanation as to why Invisalign® may score worse on ABO grading criteria may exist in the technology of the material, as well as the computer program used to create the prescription. A comparison of predicted and actual Invisalign® treatment outcomes has indicated that there is a mismatch in the translation from desired outcome to actual result. Buschang et al used the ABO Objective Grading System to compare the predicted Invisalign® ClinCheck® treatment outcome versus the actual treatment outcome using a model scanner and simulated overlap of the models using STL files.[62] The results of this study indicate that median scores for the individually graded components, as well as the total score, were increased for the actual treatment outcome models than for the ClinCheck® models. This indicated that according to ABO standards, more points were lost in the actual treatment outcomes as compared to the predicted ClinCheck® models. Differences again were noted in the occlusal contacts, among other aspects of occlusion and alignment in the final result. Like Djeu et al[4], the study by Buschang et al also took final records immediately after treatment completion to prevent any time for settling, which demonstrates a more accurate presentation of the actual occlusal contacts provided at the end of treatment. It has been noted that overcorrection should be built into the ClinCheck® program when designing the appliances with the expectation that the aligners will not be able to deliver the full prescribed movement. This is most probably due to the flexibility in the tray material[5], and with a more rigid material the teeth may be moved more accurately in accordance to the prescription written in the ClinCheck® program.

Retention

Retention appliance design varies, and can be removable or fixed. Hawley retainers generally have an anterior labial bow, whereas wraparound Hawley retainers have wire extending around the buccal of the teeth to the posterior. Essix retainers are vacuum-formed slip covers, fabricated on a stone model of the dentition. Hawley and wraparound Hawley retainers do not have occlusal coverage whereas Essix retainers do have occlusal coverage. Positioners are elastic appliances that allow the dentition to adapt to pre-determined positions. Generally, these removable appliances are worn fulltime for a specified period and nightly thereafter. Fixed bonded retainers typically are a steel wire found on the lingual of the upper or lower anterior teeth, and offer a permanent form of retention in these locations.

Many retention duration recommendations exist, though none are agreed upon nor guarantee lifelong stability of treatment outcome should retention be abandoned.[63] Likewise, any effort to determine treatment predictors or associations between increased crowding, relapse, arch form changes, or potential dental or cephalometric contributors were unsuccessful, and no predictors for stability have been found.[24,25,27] Therefore, changes due to relapse or even by natural aging can occur in anyone, and they often cannot be distinguished from one another. However, retention should be flexible enough to allow posterior occlusal adaptation to achieve improved intercuspation, while still being rigid enough to prevent relapse and sequelae from physiologic aging.

Biological Aspects of Post-Treatment Occlusal Changes

Occlusal changes can occur regardless of orthodontic treatment. This is primarily due to three components: physiologic changes due to aging[45,46], relapse to pre-treatment positions[64,65], and settling[17] to improve interocclusal stability. In an article by Bergit Thilander, suggestions and explanations for the biological causes of occlusal changes post-treatment are provided.[64] There are both rapid and slow relapse processes occurring post-treatment, with the former occurring during the initial stages of periodontal remodeling and the latter throughout life. It can be difficult to distinguish events occurring due to relapse or settling over time as opposed to those that occur physiologically with age even in untreated individuals.

Orthodontically-moved teeth are susceptible to occlusal changes in an immature periodontium. After teeth have been moved, they are most susceptible to relapse imposed by gingival fibers in the coronal third of the root.[64] Collagen within the gingiva remodel slower than fibers in the periodontal ligament.[65] Supra-alveolar fibers have been seen histologically in dogs to not have undergone complete remodeling even 232 days after dental movement, as described by Reitan.[65] For this reason, some authors advocate fibrotomy procedures to help prevent rotational relapse. Boese performed gingivectomy of supracrestal fibers of rotated teeth as well as the teeth adjacent in macacas, and saw a reduction of rotational relapse potential.[66] Though the role and effects of oxytalan, an elastic-like fiber, still need further investigation[64], it has been suggested that it contributes to orthodontic relapse[66]. In rotated non-gingivectomy control teeth in this Boese study, oxytalan was seen in higher concentration in the supracrestal transeptal regions often following the orientation of the collagen fibers.[66] Though oxytalan was increased in the rotated gingivectomized teeth, the concentration was still not as high as that found in the rotated non-surgical controls. The oxytalan in the gingivectomized group was generally not seen to be organized transseptally and fewer collagen connections existed between adjacent teeth in the area that underwent the procedure. The author therefore asserts that with fewer collagen connections interproximally, the teeth are less prone to relapse as the periodontal fibers can now reorient without the tension they had prior to the procedure. Other authors recommend severing the transeptal fibers in a CSF, or circumferential supercrestal fibrotomy procedure, rather than complete removal of them.[67,68] Another suggestion is broadening contact points by interproximal reduction in addition to CSF, as was studied and advocated by Boese to help reduce relapse.[69]

In terms of natural aging contributors, late growth is also a factor that has been suggested to cause posterior occlusal changes, because it is related to continued vertical eruption of the teeth.[70] Compensatory eruption due to occlusal wear with time also occurs to maintain occlusal contact.[43,44] Mesial migration of teeth due to mesially-directed forces[45,46] is another potential consequence of physiologic aging, and affects treated and untreated individuals alike. Arch depths and widths change overtime, typically decreasing, and crowding and relapse can result.[63] Likewise, soft tissue influences can affect tooth position as they exert forces on the dentition as well. It can be agreed upon that generally there are no established predictors of relapse potential, and lengths taken during treatment to prevent relapse do not guarantee a stable result long-term.[22]

Whereas relapse suggests a return to pre-treatment conditions, settling is the continual adaptation of teeth to achieve a more stable interocclusal relationship. The cone-funnel concept discussed by Van der Linden best characterizes the biological action of settling.[17] As teeth erupt, the palatal cusps of the maxillary molars act like cones driven into the funnel of the opposing mandibular occlusal fossae. Teeth are displaced and moved so that this optimal intermaxillary relationship can be achieved and proper interdigitation can result.

Settling can be observed in two phases; one occurring soon after treatment ends, and the other occurring throughout life. Phase I of settling can occur by teeth moving independently from one another immediately after debond, instead of as one unit bound together by wires or trays. Rapidly they displace to achieve stability with the opposing dentition. Phase II of settling is a much slower and prolonged process that occurs over the lifetime of an individual. As wear occurs with time, both compensatory vertical eruption[43,44] and mesial migration[45,46] occur to maintain opposing occlusal contact. There is limited information regarding age-related changes in ACNC, however knowing that wear and compensatory eruption occur, it can be extrapolated that absolute contact size increases with age to aid in continued settling throughout life.

Settling and Its Comparison Among Different Retainer Types

Past retention studies have primarily focused on the lower anterior teeth. A 2006 systematic review on retention procedures found that determining the best retainer type was controversial and inconclusive.[71] It was deemed that there is insufficient evidence to determine which retainer type functions the best to maintain tooth position and prevent relapse after orthodontic treatment. Though there is no consensus on best overall retention type, the literature generally supports that posterior settling does occur, and typically occurs to a greater extent with retainers that do not have occlusal coverage (Table 2).

The majority of studies indicate that orthodontic settling occurs and is often desirable after debanding to allow further posterior occlusal contact and intercuspation of the dentition in retention.[9,10,13,16,19,32,48,49,72,73] This is primarily a physiologic phenomenon mirroring what occurs naturally with age, such as continued vertical eruption of the teeth as was described previously in untreated individuals. Gazit and Lieberman utilized photo-occlusion, finding a 56% increase in contacts one year after orthodontic treatment.[72] Sultana et al utilized a pressure sensitive sheet and confirmed with a black silicone bite registration material in MIP an increase in occlusal contacts 1 year after discontinuing the retainer.[48] Sultana et al did not specify a pre-determined range of acceptability to define a contact, however.

Because Hawley retainers do not have occlusal coverage, they are reliable appliances for improving settling. Hoybjerg et al evaluated orthodontic patients at debond and at 1-year recall post-treatment.[32] Though exact numbers of contacts were not provided in the study, they did demonstrate that the upper and lower Hawley group's ABO Cast-Radiograph Evaluation (CRE) occlusal contact score improved significantly from 5.47 to 3.33 (p= 0.0245). Horton et al evaluated 22 subjects wearing Hawleys at the day of delivery and 7.8 +/- 1 weeks later.[10] Based on Blu Mousse® bite registrations, there was a significant 63% increase in ACNC over time, representing an increase from 6.71 mm^2 at T1 to 10.97 mm^2 at T2. Over 8 months of retention as was demonstrated by Bauer et al, it has been shown that ACNC increased 129% in the Hawley group, from 7.01 mm^2 at debond to 16 mm^2 at 8 months.[9] As these results demonstrate, a dramatic increase in posterior contacts can occur with Hawley retainers.

Wraparound retainers also lack posterior occlusal coverage, and can allow settling. Basciftci et al evaluated 20 post-orthodontic subjects with wraparound retainers at debond and about 14 months into retention.[73] They wore the retainers fulltime for 6 months and nightly thereafter. Perforations in bite registrations were deemed to be absolute contacts, transferred to the maxillary model, and counted. By T2, the subjects had increased from 13.93 to 17.09 contacts.

Positioners are able to detail tooth positions with small 0.25-0.5 mm movements[74], and are also capable of increasing posterior occlusal contacts. Bauer et al showed that ACNC can increase 105% over the course of 8 months of retention.[9] However, these patients wore positioners for the first two months of retention and Hawleys after this time. The increase in ACNC during the first two months with just positioner-wear was significant, increasing from 8.3 mm^2 to 13.2 mm^2. Horton et al demonstrated a significant increase in ACNC in their positioner group from 8.44 mm^2 to 13.95 mm^2 after about 2 months of retention.[10]

In a study evaluating Essix retainers, 36 Class I and Class II patients were treated orthodontically and then were randomized into a full-coverage or modified-coverage group (no occlusal coverage of the posterior teeth) for the retention period.[75] They were instructed to wear these full time for 6 months and then night only for the next 3 months. Occlusal bite registrations were acquired for contact analysis. Full-coverage Essix provided no significant increase in occlusal contacts, whereas the modified-coverage group experienced a significant increase in posterior occlusal contacts. According to Sauget et al, Essix retainers worn fulltime for 3 days and nightly thereafter show no appreciable settling during the first three months after debonding.[13] Results were a non-significant change from a mean of 23.67 posterior contacts at debond to a mean of 27.93 posterior contacts at the end of three months. Therefore, with occlusal coverage of the posterior teeth in retention, minimal to relatively no degree of settling should be expected.

Studies comparing Hawleys and positioners have reported little difference in terms of resulting posterior occlusal contacts. Durbin et al examined actual occlusal contacts in 38 patients at deband and 3 months into retention using polyether rubber impression bites at these two time points.[49] One group wearing maxillary conventional retainers (Hawleys) and mandibular removable retainers or fixed lingual arches (L3-3 or L4-4) was compared to a group wearing gnathological rubber tooth positioners. They found a 14% increase in occlusal contacts during the first 3 months of retention, which was primarily due to posterior contact increases. Though the positioner was found to be better in improving contacts than the Hawley, they noted that the difference was not of much clinical significance. Horton et al, who randomized 50 post-orthodontic patients to wear either Hawleys or Perfector retainers (i.e. a modified positioner), showed they were equally effective in increasing posterior occlusal contacts during the first two months of retention.[10]

In evaluating presence or absence of occlusal coverage, contact increases favor retainers with no occlusal coverage. The Sauget et al study compared conventional removable Hawley retainers with clear overlay retainers in terms of settling in the post-orthodontic retention period.[13] Details regarding the orthodontic treatment are limited; however the article does specify 30 consecutive departmental patients were evaluated in the study. They classified occlusal contacts as numbers of contacts that were either true or near, with true being perforations and near being translucencies less than 0.20 mm, as measured with an Iwanson caliper. Impressions were made for retainer fabrication immediately after fixed appliance removal. The protocol was for one group of patients to wear Hawleys full-time, except when eating, and another group of patients to wear clear overlay retainers full-time for the first three days and then nightly after that time. They compared vinyl polysiloxane bite registrations at 3 different time points (30 minutes after deband, at the time of retainer delivery, and three months into retention). At deband, there was no statistically significant difference detected in numbers of occlusal contacts between those patients who received Hawleys and those who received clear overlay retainers (Hawley: mean of 34.3 +/- 10.45 SD; clear overlay retainers: mean 31.8 +/- 11.8 SD). However, after 3 months into retention, there was a statistically significant difference in favor of the removable Hawley group ($p<0.05$), based on the number of posterior true contacts, near contacts, and total true contacts. The clear overlay group did not show any significant difference between the time of deband and 3 months into retention. One might expect that, given the wear-time protocol, more settling would have occurred in the clear aligners group because they had less wear time than the Hawley group. However, because these retainers were made on the newly debanded models, and also noting the thickness of plastic between the maxillary and mandibular occlusal surfaces, these may preserve any open occlusion that existed upon the day of deband, as well as prevented any further eruption to allow settling. This study shows that the plastic material on the occlusal surfaces of the clear overlay retainers is enough to hinder settling and increase in occlusal contacts in maximum intercuspation in the retention period.

Another article illustrating settling and posterior occlusal changes during retention used the ABO CRE scoring system. Hoybjerg et al compared 3 retention protocols.[32] Though all 3 groups improved their overall CRE scores as well as experienced an increase in occlusal contacts during retention, the upper Hawley and lower bonded 3-3 retainer group had the greatest statistically significant improvement in their occlusion. The upper and lower Hawley group demonstrated the next best improvement, and the least improved was the upper Essix and lower bonded 3-3 retainer group. Interestingly, many would not have passed the ABO exam compared with their 1 year post-debond records. Therefore, according to the ABO CRE standards, the cases improved over the course of this year, primarily due to settling.

Other studies have indicated that though settling may increase posterior contacts during retention, the numbers and quality may not equal untreated occlusions. Haydar et al compared occlusal contacts of patients with Hawley retainers, tooth positioners, and untreated normal occlusions.[18] After a settling period of 3 months neither of the retention groups had as many occlusal contacts as the untreated normal group. Additionally, the location of the contacts did not change over the settling period, suggesting that even though settling may increase number of contacts, it may not increase quality of the contact. Sullivan et al also showed that treated patients do not attain the same contact numbers as untreated subjects regardless of the retention duration, which in some patients was as long as 81 months post-retention.[16] Dincer et al compared bite registration records from 20 treated orthodontic patients pre-retention and 9 months post-retention to evaluate if there was a change in the number of posterior contacts within that time.[19] Though they found that there was a significant increase in posterior contacts by 9 months of retention, which was a longer retention period than in the Haydar et al study, the locations of the contacts did not improve over time.[19] Both studies agree that even if contact number improves, the location does not so the cases should be finished with as ideal an occlusion as possible prior to debonding.[18,19]

Though most articles discuss increases in occlusal contact number during retention, other research suggests that contacts may actually remain relatively the same. It has been cited that areas of actual and near contacts may not significantly improve or increase after treatment.[76] However, this study by Parkinson et al used mounted models to acquire bite registrations and assess ACNC, which do not necessarily provide the same results as those in the mouth.

Duration of Settling

In terms of duration of settling, there is no consensus on exactly how long this process takes. However, it can be extrapolated that as long as natural physiologic changes take place with age, teeth will continue to settle and adapt to these changes. Razdolsky et al determined that settling continues after the initial three months of retention.[29] Bauer et al showed that occlusal changes after 6 months of settling were not statistically significant; the greatest rate of settling occurred during the first 2 months of retention.[9]

CHAPTER III
BACKGROUND

With esthetics being a major factor in why people seek orthodontic treatment, it is natural that clear or tooth colored treatment modalities have gained popularity. Invisalign®, the most well-known clear aligner on the market, has been evaluated alone[3] as well as compared with traditional braces[2,4] in previous literature. Reported results have been controversial; literature has shown no significant change with treatment in marginal ridge ABO scores[3] whereas other research has indicated otherwise[2]. However, many studies have demonstrated a negative treatment effect on occlusal contacts with Invisalign®, even more so than in traditional braces.[2,4] These studies utilized the subjective assessment of the ABO OGS; no studies were found using the more objective ACNC method in regards to treatment effects of Invisalign® nor traditional braces.

It is known that orthodontic treatment decreases occlusal contacts[16], though studies have also declared that even despite time in retention, contacts do not equal those of untreated occlusions[18,19]. These studies focus on retention of traditional braces and not those treated with Invisalign®. Most posterior occlusal changes have been cited to occur within the first two months of retention, with non-significant changes occurring after six months.[9] Van der Linden's cone-funnel concept best describes the act of settling in retention as the occlusion settles to find an equilibrium with its cusp-fossa relationship.[17] While studies have evaluated retention after traditional braces, insufficient studies were encountered observing the retention of Invisalign® patients. The only literature found comparing Invisalign® and traditional braces in retention was one by Kuncio et al, which found that after about 3 years of retention marginal ridges and buccolingual inclinations were not significantly different between treatment groups, nor did either change significantly in retention.[20] With only one article in the literature, it is not possible to draw a definitive conclusion on the comparative results in retention of these two treatments. Likewise, no studies were found using ACNC to evaluate Invisalign® in retention nor compare it to traditional braces using the same method.

CHAPTER IV
MATERIALS AND METHODS

A sample of 44 adult subjects (median ages 27.8 and 25.4 years, respectively) with Class I malocclusion were evaluated after being randomly assigned to be treated either with Invisalign® or traditional fixed braces (Figure 14). A total of 22 subjects were in each group. The Invisalign® group consisted of 12 females and 10 males. The traditional braces group consisted of 15 females and 7 males.

Patient Selection

This randomized controlled trial (IRB approval #2012-21-BCD) was performed at Texas A&M College of Dentistry. Adults were screened and treated by two orthodontic faculty members. Records and data were evaluated by a blinded third member not involved with the treatments.

Inclusion criteria included mild crowding, Class I malocclusion, non-extraction, and adult subjects with no missing teeth (except third molars). Subjects could have crowns and/or occlusal restorations, but no broken restorations were allowed. Subjects were randomized into the two treatment groups using Microsoft® Excel (Microsoft® Corporation, Redmond WA) electronic randomization.

Patient Treatment

No extraoral appliances or additional anchorage appliances were used. Elastics were used as needed. Every Invisalign® patient underwent two refinements. The patients were instructed to wear their aligners for 22 hours per day. Each aligner was worn for two weeks. The treating orthodontist included heavy posterior occlusal contacts in the ClinCheck® to help ameliorate any posterior open bite that may occur due to the occlusal plastic of the trays. The fixed orthodontic group was treated with Alexander 018 bracket prescription (American Orthodontics©, Sheboygan WI). After treatment was completed, the retention protocol in both groups was upper wraparound Hawley and bonded lower 3-3. Seven of the subjects received at least one Essix, six received a lower gemini, and one subject's retention was not documented. The reasoning for altered retention protocol was not documented for all subjects, but for some the rationale was listed due to bruxism, intolerance of the Hawley, or patients declining bonded retention. Occasionally, upper 1-1 or 2-2 bonded retainers were included if pre-treatment diastema existed. No occlusal equilibration was performed on any patient during retention.

Data Collection

Data was collected at four time points, including pre-treatment (T1), day of debond (T2), 1 month post-treatment (T3), and 6 months post-treatment (T4). The records evaluated were Blu Mousse® bite registrations and orthodontic study models. Three individuals involved in the study were available to acquire the records. To be included in the data collection, patients had to have at least completed treatment.

Study Model Assessment

Alginate impressions were acquired and poured with orthodontic plaster to create study models, which were trimmed based on a centric occlusion bite registration. Models were evaluated based on the ABO CRE criteria, including marginal ridge discrepancy and buccolingual inclination of the posterior teeth.[31] The points were then added together in their respective categories and recorded in Excel® as total points for marginal ridges and total points for buccolingual inclination at each time point.

Bite Registration Assessment

Blu Mousse® bite registrations (VPS Bite Registration material, Parkell Inc., Edgewood NY) were taken bilaterally (Figure 1). Each registration included four teeth, from second molar to first premolar. Subjects were instructed to bite firmly on their back teeth for about 30 seconds until the material was fully set. The same brightness level of the lightbox (Huion LED Light Pad, Model L4S, Huion Technology, Shenzhen China) was used to visualize all transilluminated bite records. Right and left trimmed bite registrations were laid side by side on the lightbox, along with a time point and subject identifiers, and a millimeter ruler to ensure focus of the image (Figure 1).

A Nikon® DSLR camera (Manual setting, f6.2, ISO 100, Nikon®, Tokyo Japan) was used to photograph the transilluminated bite registrations. The camera was held by an adjustable tripod 18.6 inches from the lightbox, and directed perpendicularly to the samples on the lightbox. An opaque black fabric was placed around the camera and the lightbox to block out ambient light. A light meter was used during all photography sessions to ensure consistent lighting across the sessions.

The posterior occlusal table captured in the photographs was traced electronically, cropping everything else out of the image (Figure 2A). The outer borders of the cropped images were standardized and colored black to prevent any false white readings.

The images were then imported into Mathematica® (Wolfram Mathematica® 9 Student Edition, Wolfram Research, Champaign IL), right separately from left, where they were converted from color into grayscale (Figure 2B). Based on the grayscale image, Mathematica® determined the corresponding number of pixels at each grayscale value from 0-255 for the entire occlusal table. Pixels were converted into square millimeters by determining the area of one pixel (Equation 1). Because of the known relationship between Blu Mousse® thickness and grayscale level as determined by a step wedge (Figure 6), the areas of contact (0-50 microns) and near contact (51-350 microns) were estimated. This range of 0-350 microns has defined ACNC based on previous studies.[8] The process of obtaining ACNC from bite registrations is outlined in Figure 3.

Bite Registration Calibration

A step wedge was used to associate Blu Mousse® material thickness to a corresponding grayscale value. A spherical step wedge was created by a ball bearing (1-1/2" Chrome Steel Bearing Balls G25, BC Precision Balls, BC Trade LLC, Los Angeles CA), with 19.05 mm radius.[11] To limit variability in placement, the ball bearing was attached to an articulator so that the arc of placement would be uniform for each step wedge (Figure 4). The ball bearing was secured in white plaster with approximately 40% of its surface exposed. Blu Mousse® bite registration material was applied to a glass surface and the ball bearing was gently lowered into the material and allowed to fully set before removing the ball. Three step wedges were fabricated to acquire the best representation.

The step wedges were trimmed with a scalpel to a 20 mm square, with the ball bearing impression in the center (Figure 5A).[11] The step wedges were then transilluminated by the same lightbox used for bite registrations. The same Nikon® DSLR camera was used to photograph the transilluminated step wedges. A millimeter ruler was placed in the background to ensure focus of the image. One-quarter of each image was electronically cropped, or 10 mm x 10 mm from the center of the absolute contact point (Figure 5B).

The first step in calibration (Figure 6) was to relate thickness to distance, and the following equation of a circle was used (Equation 2):

$$(x-h)^2+(y-k)^2=r^2$$

Distance (x) can be calculated for any thickness (y), based on the center points (h,k) and the radius (r), as demonstrated by Figure 7. The center point value remained fixed at 0 (h) and 19.05 (k). Radius (r) of the ball bearing was 19.05 mm. Thicknesses (y) were designated at 50 micron intervals from 0-350 microns. The curve describing the relationship between Blu Mousse® material thickness and distances from the center of the step wedge was estimated up to 350 micron thickness (Figure 8).

The second step was to determine pixel value at distances corresponding to 50 and 350 micron thicknesses. The step wedge was converted from color into grayscale to do this (Figure 9B). Because the number of pixels in 10 mm length was known (Table 3) and the distances associated with micron thicknesses had been previously determined (Figure 8), the pixel value at those distances can be calculated based on Equation 3. For example, the number of pixels for contact and near contact of 50 and 350 microns was determined for Step Wedge #1, which had a length of 400 pixels (Table 3). From previous calculations (Figure 8), 50 microns is equivalent to 1.379 mm and 350 microns is equivalent to 3.635 mm distance.

The third and final step in calibration (Figure 6) was to convert the pixel values into their corresponding grayscales. Mathematica® was used to calculate the grayscale value at 50 and 350 microns. The 55th pixel was the outer limit of absolute contact for Step Wedge #1, and therefore determined to be equivalent to 196 grayscales per Mathematica®. The 145th pixel was the outer limit of near contact and was equivalent to 49 grayscales. Because grayscale ranges from 0-255, with 255 being pure white and 0 being pure black, it was determined for Step Wedge #1 that grayscale values 255-196 is absolute contact and grayscale values 195-49 is near contact, and beyond 49 grayscales is no contact because it is beyond 350 microns thickness. This was performed for each of the three step wedges, and the grayscale levels averaged (Table 3) to obtain the final grayscale ranges, as demonstrated in Table 4. Table 4 demonstrates how Blu Mousse® material thickness in 50 micron increments is related to grayscale ranges.

Lastly, the area of a pixel was determined so that a conversion to square millimeters could be recorded to express areas of contact and near contact. The area of a pixel was estimated to be 0.00062 mm^2 (Equation 1). This was based on a ratio (Equation 1) of the average number of pixels in 10 mm length from each of the three step wedges, which was determined to be 401.67 pixels, as demonstrated in Table 3. When Mathematica® analyzes a bite registration, it calculates the number of pixels associated with the grayscale values in these ranges listed in Table 4. When converted from number of pixels to area in square millimeters, the ACNC can be estimated (Figure 3).

Reliability

Reliability was assessed for both the bite registration and model measurements. Thirty duplicate bite registrations were acquired on randomly selected subjects to determine reliability and reproducibility of the samples. These bite replicates indicated no statistically significant systematic errors. Random error was measured using intraclass correlations and method error. Intraclass correlations of contacts (0.934, $p<0.001$) and near contacts (0.918, $p<0.001$) were high; method errors were 1.7 mm^2 for contacts and 9.6 mm^2 for near contacts. Forty-two duplicate model measurements of marginal ridges and buccolingual inclination were also performed to evaluate reliability. No statistically significant systematic error was found. Method errors for marginal ridge and buccolingual inclination measurements were 0.6 and 0.5, respectively**.** Intraclass correlations of marginal ridges (0.891, $p<0.001$) and buccolingual inclinations (0.879, $p<0.001$) were high.

Statistical Procedures

Statistics were analyzed by SPSS (Version 23.0, IBM, Armonk NY). Because ages at T1 and T2 were not normally distributed, medians were used to describe central tendencies. Durations between timepoints were normally distributed. For each measure, two analyses were performed. The mixed-longitudinal analysis included all subjects at all timepoints; the longitudinal analysis included only subjects who had records at all four timepoints. As is common in prospective clinical research, attrition of subjects over the course of the study occurred. The mixed-longitudinal analysis emphasized pre-treatment to debond results and longitudinal analysis best described information about changes that occurred post-treatment. Paired t-tests were used to evaluate group differences and independent t-tests evaluated differences within groups; means were used to describe the mixed-longitudinal and longitudinal analyses.

CHAPTER V
RESULTS

Sample Analysis

The Invisalign® group was 27.8 and 29.3 years of age at pre-treatment and debond, respectively. The median ages at pre-treatment and debond for the traditional braces group were 25.4 and 26.9, respectively. There was no statistically significant age difference between groups at either T1 ($p=0.814$) or T2 ($p=0.680$). The duration of treatment was significantly longer in the Invisalign® than traditional braces group (1.97 versus 1.41 years, respectively) ($p<0.001$) (Table 5). The duration between T2-T3 for the Invisalign® group was 0.15 years, which was statistically significantly longer than the 0.09 year duration of the traditional braces group ($p=0.007$). There were no statistically significant group differences between T3-T4 ($p=0.058$) or T2-T4 ($p=0.328$).

Areas of Contact (≤50µ)

Areas of contact decreased during treatment and increased during the first month post-treatment. The mixed-longitudinal and longitudinal analyses (Figures 10A, 10C) showed that areas of contact decreased between T1-T2 in both groups. The mixed-longitudinal decreases of both groups, as well as the longitudinal decrease of the Invisalign® group between T1-T2 were statistically significant ($p<0.05$) (Figures 10B, 10D). Both groups also showed increases in contact area between T2-T3, but only the Invisalign® group showed a statistically significant increase ($p=0.015$ in mixed longitudinal data and $p=0.047$ in longitudinal data) (Figures 10B, 10D). The changes that occurred between T3-T4 were not statistically significant for either group (Figures 10B, 10D). At T4, traditional braces showed higher areas of contact than Invisalign®, but only the mixed-longitudinal group difference was statistically significant ($p=0.030$) (Figure 10A). The longitudinal analysis did not demonstrate statistically significant between-group differences at any time point (Figure 10C).

Near Contacts (51-350µ)

Areas of near contact followed the same pattern as areas of contact. According to both the mixed-longitudinal and longitudinal analyses, they decreased between T1-T2 (Figures 11A, 11C). The mixed-longitudinal analysis showed a statistically significant decrease in near contacts in both the Invisalign® and traditional braces groups ($p<0.001$, $p=0.014$) (Figure 11B); the longitudinal analyses demonstrated a statistically significant decrease only in the Invisalign® group ($p=0.009$) (Figure 11D). Increases in areas of near contact were evident in both groups between T2-T3 and T3-T4, but only the changes between T2-T3 were statistically significant (Figures 11B, 11D).

Marginal Ridges

Starting marginal ridge points were low. The mixed-longitudinal analyses showed 2.14 and 1.85 mean marginal ridge points for the Invisalign® and traditional braces groups, respectively. Mixed-longitudinal analysis demonstrated decreases in mean marginal ridge points between T1-T2 in both groups, but neither was statistically significant. Neither the mixed-longitudinal nor longitudinal analyses showed statistically significant within-group or between-group differences between T1-T2, T2-T3, nor T3-T4 (Figures 12A-D).

Buccolingual Inclination

Starting buccolingual inclination points were also low, approximating 2.7 and 2.0 for mean points for the Invisalign® and traditional braces groups, respectively. The analyses demonstrated no statistically significant changes in buccolingual inclination in either group between any timepoints (Figures 13A-D). There also were no statistically significant between-group differences at any timepoint.

CHAPTER VI
DISCUSSION

Prior to treatment, the patients in the present study had relatively large ACNC, indicative of good posterior occlusion. Pre-treatment mean areas of contact were 14.2 mm^2 and 11.8 mm^2 in the Invisalign® and traditional braces groups, respectively (Figure 10A). Areas of near contact were approximately 6 times higher. The ACNC in the present study were substantially higher than the 2 mm^2 of contact and approximately 35 mm^2 and 47 mm^2 of ACNC reported by Owens et al for the first molars and premolars of untreated subjects with Class I malocclusion and normal occlusion, respectively.[8] Assuming that the second molars provide approximately 30% of the ACNC of the posterior occlusal table, the present study's ACNC would still be nearly twice as large as those with Class I malocclusion. Lepley et al, who evaluated ACNC of 30 subjects with Class I occlusion, reported higher areas of contact than the present study, but smaller areas of near contact than in the present study.[7] Although Lepley et al included second molar to first premolar in their analyses, their ACNC ranged 0-250µ, instead of the 0-350µ used in the present study, which could account for some of the differences. Importantly, Lepley and coworkers evaluated dental students and dental school staff, who might be expected to have better than average Class I occlusion. Differences between studies could also be attributed to different bite registration collection and analysis techniques.

The patients' initial mean marginal ridge and buccolingual inclinations also indicated good initial occlusion in the present study. Mean pre-treatment marginal ridge relationships and buccolingual inclination ranged from 1.9-2.1 and 2.0-2.7, respectively (Figure 12A, 13A). Given that the maximum number of points possible for either category could be 20, the pre-treatment values in the present study represent 10% of the maximum possible. Pre-treatment posterior occlusion of the patients in the present study was better than previously reported for patients post-treatment. Post-treatment marginal ridges have been reported to be 119-292% of those in the present study.[4,33,34] Post-treatment buccolingual inclinations have ranged from 25% less in one study[33], with other studies[4,34] increasing up to 370% from the initial mean values in the present study. If the initial marginal ridge alignment and posterior torques do not deviate significantly from ideal, little or no change in these values might be expected with treatment and through retention.

Posterior occlusion worsens during orthodontic treatment. ACNC for the Invisalign® group decreased 54-75% during orthodontic treatment in the present study. Similarly, ACNC for traditional braces decreased 70-75%. Though there are no previous studies that have compared pre- and post-treatment ACNC, Sullivan et al showed that the number of posterior contacts decreased significantly after 1 month of treatment, and did not increase significantly over the next 11 months of orthodontic treatment.[16] Posterior open bites reported with clear aligner therapy due to the plastic thickness of the trays[5] could also decrease ACNC. Posterior occlusion might be expected to worsen during orthodontic treatment due to moving the locations of point contacts, which decreases areas of near contact. The pre-treatment equilibrium created by wear and function are changed with orthodontic treatment, decreasing ACNC. With teeth bound together as a unit in treatment, individual teeth are prevented from finding an equilibrium with the opposing dentition.

Most of the improvement in posterior occlusion occurs during the first month of retention in both groups. ACNC increased approximately 25-94% from debond to 1 month; despite numerical increases, there were no significant increases in ACNC seen T3-T4 in either group. This indicates that most of the settling occurred within the first month of retention, which supports the idea of Phase I settling. Once appliances are removed and teeth move independently, they can establish equilibrium with the opposing dentition. The rapid increase in the first month of retention and the decelerating rate between one and six month of retention mirrors the results of Bauer et al; they showed that the greatest rate of settling occurs within the first two months of retention, with decelerating rate between two and six months.[9] The rapid settling that occurs early in retention could be attributed to Van der Linden's cone-funnel concept, which emphasizes the importance of central fossae guiding cusps into maximum interdigitation during eruption.[17] Despite initial occlusal contacts, teeth continue to be guided into a more stable position, which increases the number of contacts.

While posterior occlusion improves post-treatment, it does not attain pre-treatment values after 6 months of retention. In the end of the present study, ACNC were at 23-96% of their pre-treatment values. It has been previously shown that contacts increase during retention[9,10], but they do not equal pre-treatment or untreated normal occlusions even after 81 months of retention[16,18]. Six months may be too short a time period to wear the dentition or experience compensatory eruption[42,43] and Phase II settling, thereby limiting the increase of ACNC. Likewise, no occlusal equilibration was done to aid settling in the present study. Although there is no literature directly linking occlusal wear, compensatory eruption, or equilibration with ACNC, they might be expected to increase over time due to these factors.

Invisalign® and traditional braces produce similar changes in ACNC during treatment. None of the analyses indicated between-group differences in ACNC over the course of treatment. This contradicts the commonly held belief that posterior open bite is a potential side effect of clear aligner therapy.[5] ACNC of patients treated with Invisalign® and traditional braces have not been previously compared. However, studies have used other methods to evaluate posterior occlusion at the end of treatment. Djeu et al utilized the ABO OGS and found that post-treatment occlusal contacts were significantly worse in patients treated with Invisalign® than in those treated with traditional braces.[4] The comparable treatment result between the two groups could be due to the Invisalign® group receiving two refinements, as well as the treating orthodontist building in heavier posterior contacts into the ClinCheck® to decrease the likelihood of posterior open bites.

Likewise, both treatment groups showed similar changes in ACNC during the first 6 months of retention. Most of the analyses in the present study showed no group differences in ACNC during retention. However, the mixed-longitudinal analysis showed a significant difference favoring the traditional group 6 months post-treatment, though the difference was numerically small. When comparing identical sample sizes in the longitudinal analysis, this difference disappeared and there was no group difference at any time point. No studies were available comparing ACNC in retention of these treatments. However, because the present study indicates that treatments finish similarly, they should also settle similarly, thus explaining the non-statistically significant differences between groups.

Marginal ridges and buccolingual inclination of the patients are similar at the end of both treatments. Both analyses demonstrated no significant within-group or between-group changes between pre-treatment and debond. Kassas et al demonstrated that buccolingual inclinations improved with Invisalign®, but marginal ridges did not.[3] As in the present study, Djeu et al showed that braces and Invisalign® treated marginal ridges similarly to one another.[4] However, they showed opposing results on buccolingual inclination, which were worse with Invisalign® than with traditional braces. Therefore, there is some discrepancy in the literature regarding the true effects of Invisalign® on marginal ridges and buccolingual inclination, as well as how it compares with traditional braces. In the current study, because the pre-treatment discrepancy in marginal ridges and buccolingual inclinations was low, there wasn't much orthodontic correction needed.

Likewise, marginal ridges and buccolingual inclinations change similarly throughout 6 months of retention. None of the analyses demonstrated significant between-group or within-group changes during 6 months of retention in terms of marginal ridges and buccolingual inclination. Limited information is available comparing changes during retention of these two groups. However, one study found after approximately 3 years of retention, no significant differences existed between groups in marginal ridges or buccolingual inclination in those treated with Invisalign® versus traditional braces.[20] Because subjects finished treatment similarly, it would be expected that their post-treatment changes in marginal ridges and buccolingual inclination would also be similar.

Despite no significant group differences, numerical differences exist between the groups. The mean treatment time was significantly longer for Invisalign® than traditional braces by approximately half a year. This could be attributed to the two refinements included with Invisalign® treatment. The longitudinal analysis showed that areas of contact increased about 25% one month after braces were removed, and approximately 94% during the same time period after Invisalign® was completed (Figured 10C, 10D). Due to the thickness of plastic, the Invisalign® patients most probably had more interocclusal distance to travel in order to accumulate more occlusal contacts during retention. Additionally, the mean duration of time between T2-T3 for the Invisalign® group was approximately 2.5 weeks longer than the traditional braces group; Invisalign® T2-T3 elapsed time was just under 2 months, whereas the mean duration of time was just over 1 month for traditional braces, and therefore Invisalign® had a slightly longer duration to increase contact number. Retention through 6 months demonstrated a 23% return to pre-treatment contact area in Invisalign®, whereas traditional braces experienced a 90% return. Longitudinal analysis of areas of near contact showed that Invisalign® reached about 61%, whereas braces reached approximately 96% of pre-treatment value. Though these percentage comparisons seem large, it is important to realize that numerically Invisalign® started with higher pre-treatment ACNC than traditional braces, decreased more during treatment, and therefore had numerically more ACNC to recover. The statistical difference between groups favoring traditional braces at T4 as shown by the mixed-longitudinal analysis of areas of contact could be attributed to a difference in sample size between the groups. When evaluating identical sample sizes, these differences disappear. Though no group differences exist for ACNC or the ABO OGS measurements, it is important to evaluate the numerical differences to better understand their contributions to the overall results.

The present study had limitations that could have impacted the results. First, compliance with the retention protocols by both the treating doctors and the patients was not ideal. Not all patients followed the same retention protocol (i.e. upper wraparound Hawley and bonded L3-3). Some patients refused bonded retainers or were given lower

Hawley retainers when judged appropriate by the treating doctor. The treating doctors also delivered Essix if bruxism was present. It is also possible that some Invisalign® subjects chose to wear their final tray as their retainer if they did not like the Hawley. Thirty subjects received the study's retention protocol (12 Invisalign® subjects, 18 traditional braces subjects), 7 received at least one Essix (3 Invisalign® subjects, 4 traditional braces), 6 received a lower gemini (6 Invisalign® subjects, 0 traditional braces), and 1 subject had unknown retention (1 Invisalign® subject). However, a nearly equal number of subjects in both groups received at least one Essix retainer, which has been shown to have the greatest effect on post-treatment settling.[13,75] Because compliance was not assessed, group differences in retainer wear remains unknown. Morphology of pre-treatment restorations was not evaluated in this study; if restorations were contoured improperly prior to treatment, settling could be affected. Subject recall after debond was another challenge. Several subjects missed data collection appointments and then could not be reached to reschedule their appointment. Additionally, since the amount of time available for the study was limited, only subjects who were finished with treatment could be included. For the same reason, some of the patients had not been out of treatment long enough to collect the 1 and 6 month records, which affected sample size. Additionally, because the T2 timepoint was added after the study had already started, not all subjects had a T2 record, which decreased sample size. A larger sample would be required to definitively state non-significance.

The clinical implications of this study help to improve treatment outcome as well as long-term stability of the occlusion. Knowing that the interocclusal thickness of the plastic trays can impede occlusal contacts[2,4,5], it is important to combat this by building in heavy posterior occlusal contacts in the Invisalign® ClinCheck®. Likewise, using a retention protocol that does not have occlusal coverage can allow more settling.[13,32,73] Though settling occurs most significantly within the first month of retention, it continues through six months post-treatment. However, masticatory performance may be compromised[7,8] by orthodontic treatment due to decreasing areas of contact and near contact. Previous literature demonstrated that though normal and malocclusion classes all had approximately equal contact area, normal occlusion had larger near contact areas than Class I, II, or III malocclusion.[8] The normal subjects also were better able to break down CutterSil® samples, therefore demonstrating that near contacts are even more important in determining masticatory efficiency. In order to achieve the most contact number, area, and best location, equilibration of occlusal interferences after the initial few months of significant settling may be recommended to help guide the dentition into a more stable position[77,78] during retention and improve ACNC in static and functional positions. Because pre-treatment values are not regained in retention[16,18], it is critical to finish patients optimally so that effective equilibration can be performed to improve the dentition in retention[16,78].

CHAPTER VII
CONCLUSION

Based on ACNC, marginal ridges, and buccolingual inclinations, the patients in the present study had good posterior occlusion prior to orthodontic treatment. With treatment, posterior ACNC worsened in both groups. The greatest occlusal improvement occurred during the first month of retention in both groups, with no significant changes thereafter. Importantly, post-treatment ACNC were lower than pre-treatment ACNC even after 6 months of retention, regardless of treatment modality. Marginal ridge and buccolingual inclination values did not change significantly during treatment or retention. No significant between-group differences occurred at the end of orthodontic treatment, nor throughout retention in ACNC, marginal ridges, or buccolingual inclinations according to longitudinal analyses, indicating similar treatment outcomes and settling among the two groups.

REFERENCES

1. Buschang PH, Shaw SG, Ross M, Crosby D, Campbell PM. Comparative time efficiency of aligner therapy and conventional edgewise braces. Angle Orthod 2014;84:391-396.

2. Li W, Wang S, Zhang Y. The effectiveness of the Invisalign appliance in extraction cases using the the ABO model grading system: a multicenter randomized controlled trial. Int J Clin Exp Med 2015;8:8276-8282.

3. Kassas W, Al-Jewair T, Preston CB, Tabbaa S. Assessment of Invisalign treatment outcomes using the ABO Model Grading System. Journal of the World Federation of Orthodontists 2013;2:e61-e64.

4. Djeu G, Shelton C, Maganzini A. Outcome assessment of Invisalign and traditional orthodontic treatment compared with the American Board of Orthodontics objective grading system. Am J Orthod Dentofacial Orthop 2005;128:292-298; discussion 298.

5. Vlaskalic V, Boyd RL. Clinical evolution of the Invisalign appliance. J Calif Dent Assoc 2002;30:769-776.

6. Millstein P, Maya A. An evaluation of occlusal contact marking indicators. A descriptive quantitative method. J Am Dent Assoc 2001;132:1280-1286; quiz 1319.

7. Lepley CR, Throckmorton GS, Ceen RF, Buschang PH. Relative contributions of occlusion, maximum bite force, and chewing cycle kinematics to masticatory performance. Am J Orthod Dentofacial Orthop 2011;139:606-613.

8. Owens S, Buschang PH, Throckmorton GS, Palmer L, English J. Masticatory performance and areas of occlusal contact and near contact in subjects with normal occlusion and malocclusion. Am J Orthod Dentofacial Orthop 2002;121:602-609.

9. Bauer EM, Behrents R, Oliver DR, Buschang PH. Posterior occlusion changes with a Hawley vs Perfector and Hawley retainer. A follow-up study. Angle Orthod 2010;80:853-860.

10. Horton JK, Buschang PH, Oliver DR, Behrents RG. Comparison of the effects of Hawley and perfector/spring aligner retainers on postorthodontic occlusion. Am J Orthod Dentofacial Orthop 2009;135:729-736.

11. Allen SP. Occlusal Contact of Milled Polyurethane Casts Mounted in a Proprietary and Semi-Adjustable Articulator: A Thesis Prosthodontics: Texas A&M Baylor College of Dentistry; 2015.

12. Korioth TW. Number and location of occlusal contacts in intercuspal position. J Prosthet Dent 1990;64:206-210.

13. Sauget E, Covell DA, Jr., Boero RP, Lieber WS. Comparison of occlusal contacts with use of Hawley and clear overlay retainers. Angle Orthod 1997;67:223-230.

14. Ricketts RM. Occlusion--the medium of dentistry. J Prosthet Dent 1969;21:39-60.

15. Bakke M, Holm B, Jensen BL, Michler L, Moller E. Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. Scand J Dent Res 1990;98:149-158.

16. Sullivan B, Freer TJ, Vautin D, Basford KE. Occlusal contacts: comparison of orthodontic patients, posttreatment patients, and untreated controls. J Prosthet Dent 1991;65:232-237.

17. van der Linden FP. Development of the Dentition. Quintessence Publishing; 1983.

18. Haydar B, Ciger S, Saatci P. Occlusal contact changes after the active phase of orthodontic treatment. Am J Orthod Dentofacial Orthop 1992;102:22-28.

19. Dincer M, Meral O, Tumer N. The investigation of occlusal contacts during the retention period. Angle Orthod 2003;73:640-646.

20. Kuncio D, Maganzini A, Shelton C, Freeman K. Invisalign and traditional orthodontic treatment postretention outcomes compared using the American Board of Orthodontics objective grading system. Angle Orthod 2007;77:864-869.

21. Sakamoto S, Hara T, Kurozumi A, Oka M, Kuroda-Ishimine C, Araki D et al. Effect of occlusal rehabilitation on spatial memory and hippocampal neurons after long-term loss of molars in rats. J Oral Rehabil 2014;41:715-722.

22. Little RM. Stability and relapse of mandibular anterior alignment: University of Washington studies. Semin Orthod 1999;5:191-204.

23. Little RM, Riedel RA. Postretention evaluation of stability and relapse--mandibular arches with generalized spacing. Am J Orthod Dentofacial Orthop 1989;95:37-41.

24. Little RM, Riedel RA, Stein A. Mandibular arch length increase during the mixed dentition: postretention evaluation of stability and relapse. Am J Orthod Dentofacial Orthop 1990;97:393-404.

25. de la Cruz A, Sampson P, Little RM, Artun J, Shapiro PA. Long-term changes in arch form after orthodontic treatment and retention. Am J Orthod Dentofacial Orthop 1995;107:518-530.

26. Park H, Boley JC, Alexander RA, Buschang PH. Age-related long-term posttreatment occlusal and arch changes. Angle Orthod 2010;80:247-253.

27. Sinclair PM, Little RM. Maturation of untreated normal occlusions. Am J Orthod 1983;83:114-123.

28. Okeson JP. Evolution of occlusion and temporomandibular disorder in orthodontics: Past, present, and future. Am J Orthod Dentofacial Orthop 2015;147:S216-223.

29. Razdolsky Y, Sadowsky C, BeGole EA. Occlusal contacts following orthodontic treatment: a follow-up study. Angle Orthod 1989;59:181-185; discussion 186.

30. Garrido Garcia VC, Garcia Cartagena A, Gonzalez Sequeros O. Evaluation of occlusal contacts in maximum intercuspation using the T-Scan system. J Oral Rehabil 1997;24:899-903.

31. Casko JS, Vaden JL, Kokich VG, Damone J, James RD, Cangialosi TJ et al. Objective grading system for dental casts and panoramic radiographs. American Board of Orthodontics. Am J Orthod Dentofacial Orthop 1998;114:589-599.

32. Hoybjerg AJ, Currier GF, Kadioglu O. Evaluation of 3 retention protocols using the American Board of Orthodontics cast and radiograph evaluation. Am J Orthod Dentofacial Orthop 2013;144:16-22.

33. Cook DR, Harris EF, Vaden JL. Comparison of university and private-practice orthodontic treatment outcomes with the American Board of Orthodontics objective grading system. Am J Orthod Dentofacial Orthop 2005;127:707-712.

34. Yang-Powers LC, Sadowsky C, Rosenstein S, BeGole EA. Treatment outcome in a graduate orthodontic clinic using the American Board of Orthodontics grading system. Am J Orthod Dentofacial Orthop 2002;122:451-455.

35. Bakke M. Bite Force and Occlusion. Seminars in Orthodontics 2006;12:120-126.

36. Ming-Lun H, Palla S, Gallo LM. Sensitivity and Reliability of the T-Scan System for Occlusal Analysis. Die Sensibilität und Zuverlässigkeit des T-Scan für die Okklusionanlyse. 1992;6:17-23.

37. Gazit E, Fitzig S, Lieberman MA. Reproducibility of occlusal marking techniques. The Journal of Prosthetic Dentistry 1986;55:505-509.

38. Sakaguchi RL, Anderson GC, DeLong R. Digital imaging of occlusal contacts in the intercuspal position. J Prosthodont 1994;3:193-197.

39. Da Costa FF, Santos GS, Farias-Neto A, Sanchez-Ayala A, Rizzatti-Barbosa CM. The relationship between occlusal support and maxillary development: An animal study. Eur J Dent 2015;9:400-403.

40. Farias-Neto A, Martins AP, Rizzatti-Barbosa CM. The effect of loss of occlusal support on mandibular morphology in growing rats. Angle Orthod 2012;82:242-246.

41. Ostyn JM, Hons I, Maltha JC, van 't Hof MA, van der Linden FP. Contribution of interdigitation to the occlusal development of the dentition in Macaca fascicularis. Eur J Orthod 1997;19:531-542.

42. Ostyn JM, Maltha JC, van 't Hof MA, van der Linden FP. The role of interdigitation in sagittal growth of the maxillomandibular complex in Macaca fascicularis. Am J Orthod Dentofacial Orthop 1996;109:71-78.

43. Whittaker DK, Molleson T, Daniel AT, Williams JT, Rose P, Resteghini R. Quantitative assessment of tooth wear, alveolar-crest height and continuing eruption in a Romano-British population. Arch Oral Biol 1985;30:493-501.

44. Whittaker DK, Griffiths S, Robson A, Roger-Davies P, Thomas G, Molleson T. Continuing tooth eruption and alveolar crest height in an eighteenth-century population from Spitalfields, east London. Arch Oral Biol 1990;35:81-85.

45. Richardson ME. Late lower arch crowding: the aetiology reviewed. Dent Update 2002;29:234-238.

46. Southard TE, Behrents RG, Tolley EA. The anterior component of occlusal force. Part 2. Relationship with dental malalignment. Am J Orthod Dentofacial Orthop 1990;97:41-44.

47. Harris EF, Behrents RG. The intrinsic stability of Class I molar relationship: a longitudinal study of untreated cases. Am J Orthod Dentofacial Orthop 1988;94:63-67.

48. Sultana MH, Yamada K, Hanada K. Changes in occlusal force and occlusal contact area after active orthodontic treatment: a pilot study using pressure-sensitive sheets. J Oral Rehabil 2002;29:484-491.

49. Durbin DS, Sadowsky C. Changes in tooth contacts following orthodontic treatment. Am J Orthod Dentofacial Orthop 1986;90:375-382.

50. Riise C, Ericsson SG. A clinical study of the distribution of occlusal tooth contacts in the intercuspal position at light and hard pressure in adults. J Oral Rehabil 1983;10:473-480.

51. Ikebe K, Matsuda K, Kagawa R, Enoki K, Yoshida M, Maeda Y et al. Association of masticatory performance with age, gender, number of teeth, occlusal force and salivary flow in Japanese older adults: is ageing a risk factor for masticatory dysfunction? Arch Oral Biol 2011;56:991-996.

52. English JD, Buschang PH, Throckmorton GS. Does malocclusion affect masticatory performance? Angle Orthod 2002;72:21-27.

53. Helkimo E, Carlsson GE, Helkimo M. Chewing efficiency and state of dentition. A methodologic study. Acta Odontol Scand 1978;36:33-41.

54. Buschang P. Masticatory ability and performance: the effects of mutilated and maloccluded dentitions Seminars in Orthodontics 2006;12:92-101.

55. Berry DC, Singh BP. Daily variations in occlusal contacts. J Prosthet Dent 1983;50:386-391.

56. Molligoda MA, Abuzar M, Berry DC. Measuring diurnal variations in the dispersion of occlusal contacts. J Prosthet Dent 1988;60:235-238.

57. Proffit WR, Prewitt JR, Baik HS, Lee CF. Video microscope observations of human premolar eruption. J Dent Res 1991;70:15-18.

58. Kesling HD. Coordinating the predetermined pattern and tooth positioner with conventional treatment. Am J Orthod Oral Surg 1946;32:285-293.

59. Phan X, Ling PH. Clinical limitations of Invisalign. J Can Dent Assoc 2007;73:263-266.

60. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: A systematic review. Angle Orthod 2015;85:881-889.

61. Lagravere MO, Flores-Mir C. The treatment effects of Invisalign orthodontic aligners: a systematic review. J Am Dent Assoc 2005;136:1724-1729.

62. Buschang PH, Ross M, Shaw SG, Crosby D, Campbell PM. Predicted and actual end-of-treatment occlusion produced with aligner therapy. Angle Orthod 2014.

63. Little RM, Riedel RA, Artun J. An evaluation of changes in mandibular anterior alignment from 10 to 20 years postretention. Am J Orthod Dentofacial Orthop 1988;93:423-428.

64. Thilander B. Biological Basis for Orthodontic Relapse. Seminars in Orthodontics 2000;6:195-205.

65. Reitan K. Tissue rearrangement during retention of orthodontically rotated teeth. Angle Orthodontist 1959;29:105-113.

66. Boese LR. Increased stability of orthodontically rotated teeth following gingivectomy in Macaca nemestrina. Am J Orthod 1969;56:273-290.

67. Edwards JG. A long-term prospective evaluation of the circumferential supracrestal fiberotomy in alleviating orthodontic relapse. Am J Orthod Dentofacial Orthop 1988;93:380-387.

68. Taner TU, Haydar B, Kavuklu I, Korkmaz A. Short-term effects of fiberotomy on relapse of anterior crowding. Am J Orthod Dentofacial Orthop 2000;118:617-623.

69. Boese L. Fiberotomy and Reproximation Without Lower Retention 9 Years in Retrospect: Part II. Angle Orthodontist 1980;50:169-178.

70. Liu SS, Buschang PH. How does tooth eruption relate to vertical mandibular growth displacement? Am J Orthod Dentofacial Orthop 2011;139:745-751.

71. Littlewood SJ, Millett DT, Doubleday B, Bearn DR, Worthington HV. Retention procedures for stabilising tooth position after treatment with orthodontic braces. Cochrane Database Syst Rev 2006:Cd002283.

72. Gazit E, Lieberman MA. Occlusal contacts following orthodontic treatment. Measured by a photocclusion technique. Angle Orthod 1985;55:316-320.

73. Basciftci FA, Uysal T, Sari Z, Inan O. Occlusal contacts with different retention procedures in 1-year follow-up period. Am J Orthod Dentofacial Orthop 2007;131:357-362.

74. Pravindevaprasad A, Therese BA. Tooth positioners and their effects on treatment outcome. J Nat Sci Biol Med 2013;4:298-301.

75. Aslan BI, Dincer M, Salmanli O, Qasem MA. Comparison of the effects of modified and full-coverage thermoplastic retainers on occlusal contacts. Orthodontics (Chic.) 2013;14:e198-208.

76. Parkinson CE, Buschang PH, Behrents RG, Throckmorton GS, English JD. A new method of evaluating posterior occlusion and its relation to posttreatment occlusal changes. Am J Orthod Dentofacial Orthop 2001;120:503-512.

77. Clark GT, Adler RC. A critical evaluation of occlusal therapy: occlusal adjustment procedures. J Am Dent Assoc 1985;110:743-750.

78. Olsson M, Lindqvist B. Occlusal interferences in orthodontic patients before and after treatment, and in subjects with minor orthodontic treatment need. Eur J Orthod 2002;24:677-687.

APPENDIX A

FIGURES

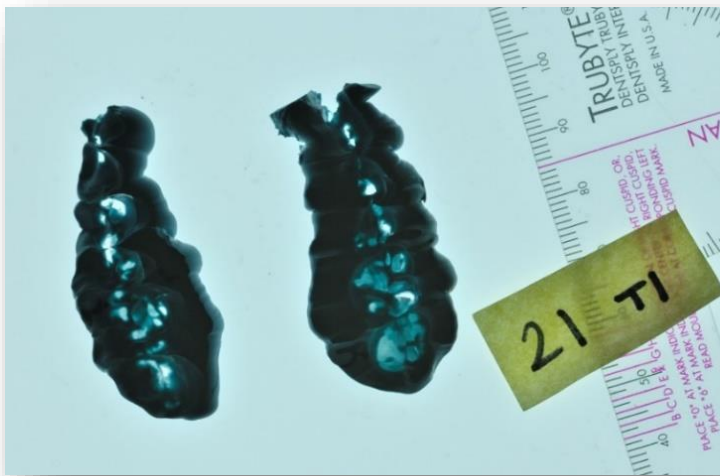

Figure 1: Example of transilluminated bite registrations

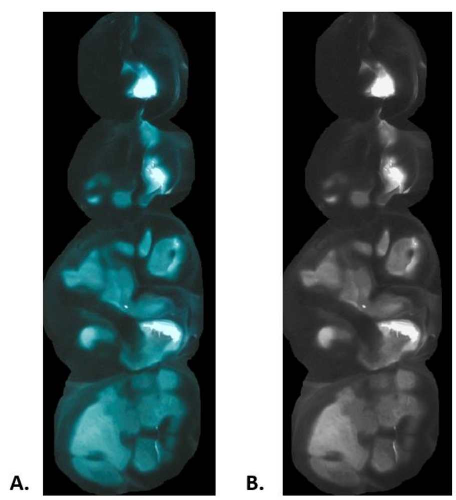

Figure 2: (A) Color version of right side posterior occlusal table (B) Grayscale version of right side posterior occlusal table

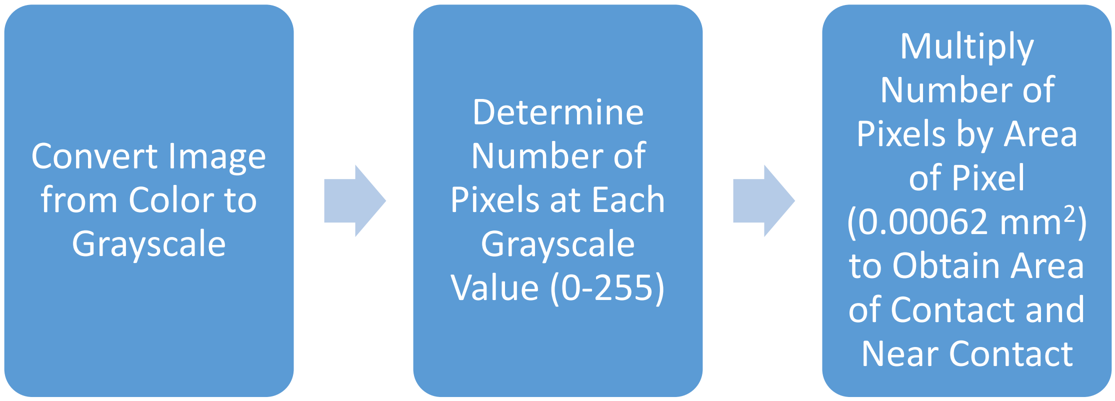

Figure 3: Process to determine ACNC from bite registration image

Figure 4: Ball bearing secured to articulator, resting on glass surface

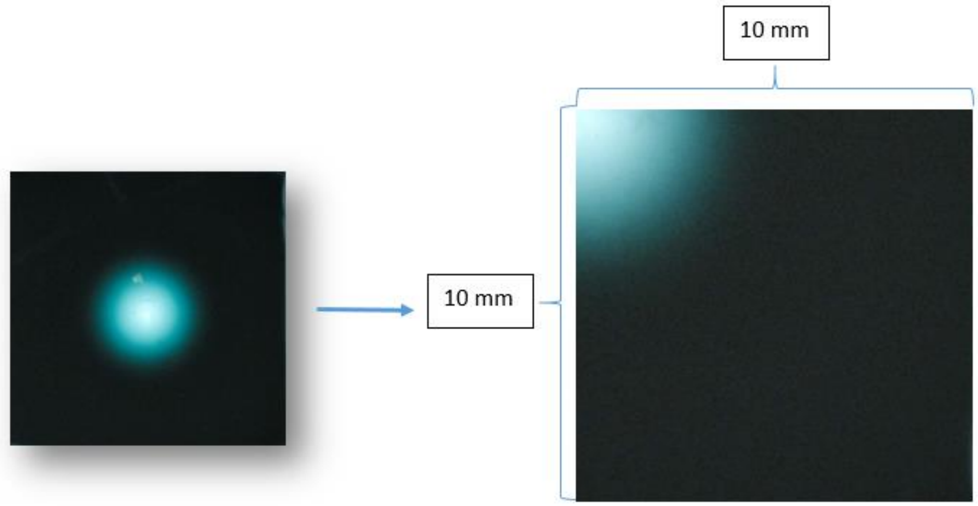

Figure 5: (A) Photo of transilluminated step wedge (B) Cropped 10x10 mm quarter of step wedge

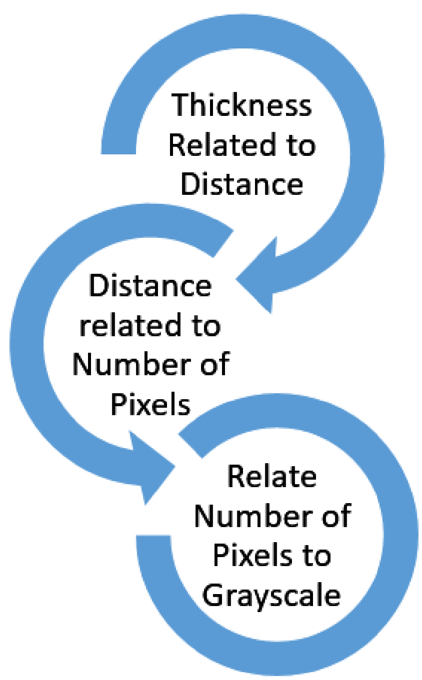

Figure 6: Relating thickness of Blu Mousse® to grayscale as determined by a step wedge

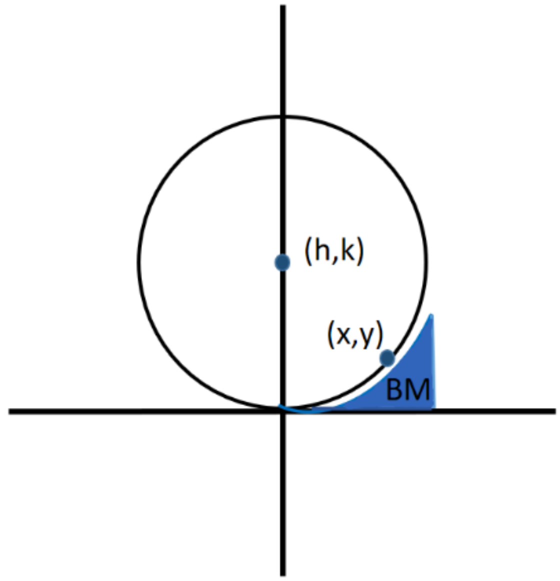

Figure 7: Depiction of sphere placed in Blu Mousse® (BM) on Cartesian coordinate system

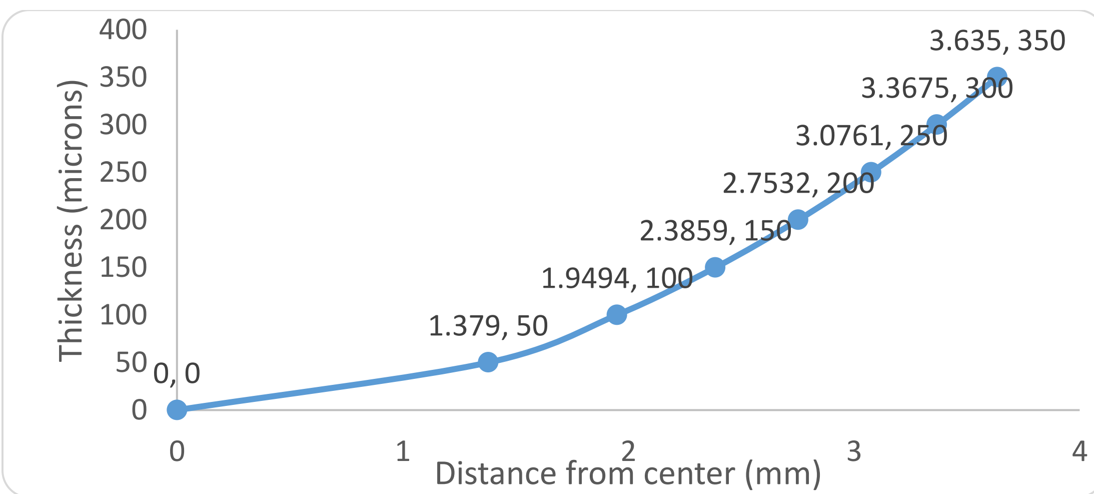

Figure 8: Illustration of distance from center (x) of the step wedge (0,0) to distance corresponding to designated 50 micron thicknesses (y)

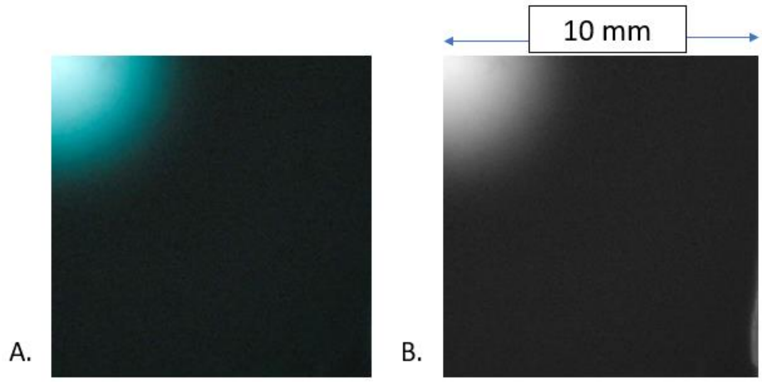

Figure 9: (A) Cropped step wedge in color (B) Cropped step wedge converted to grayscale

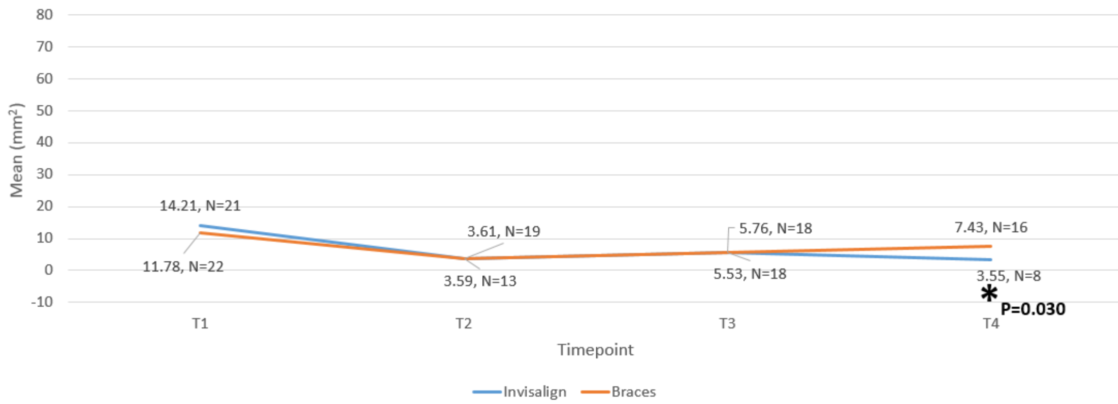

Figure 10A: Mean areas of contact (≤50μ) at T1 (pre-treatment), T2 (debond), T3 (1 month post-treatment), and T4 (6 months post-treatment) for mixed-longitudinal analysis

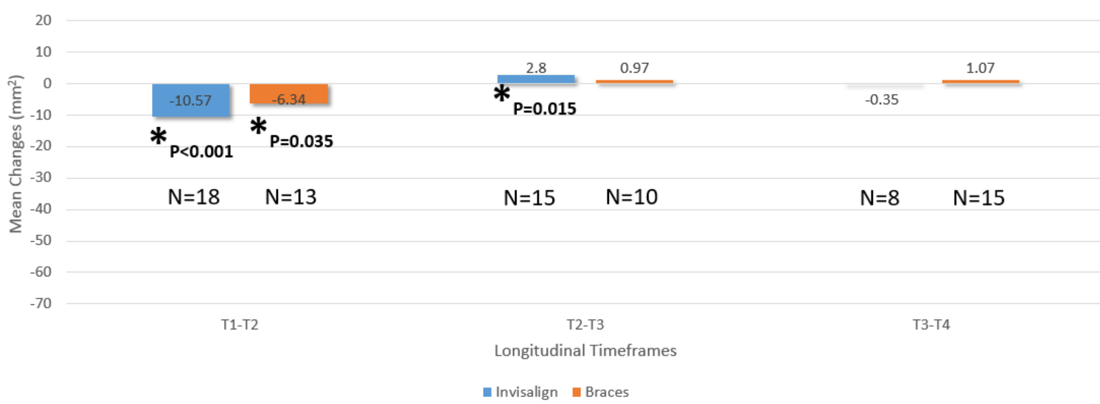

Figure 10B: Mean changes in areas of contact (≤50μ) between T1 (pre-treatment) and T2 (debond), T2-T3 (1 month post-treatment), and T3-T4 (6 months post-treatment) for mixed-longitudinal analysis

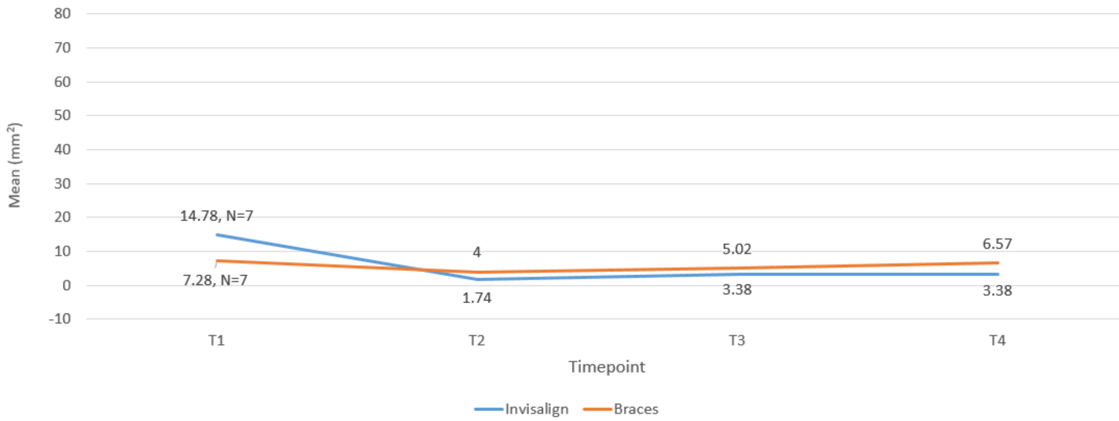

Figure 10C: Mean areas of contact (≤50μ) at T1 (pre-treatment), T2 (debond), T3 (1 month post-treatment), and T4 (6 months post-treatment) for longitudinal analysis

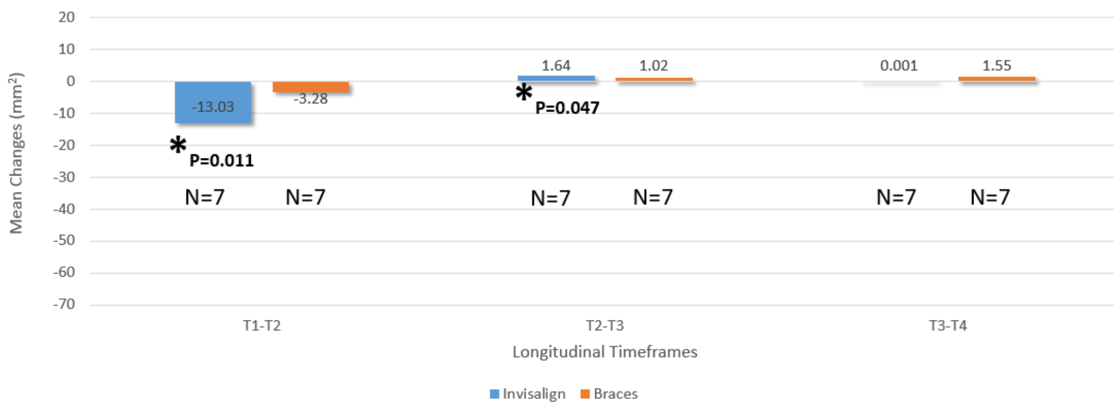

Figure 10D: Mean changes in areas of contact (≤50μ) between T1 (pre-treatment) and T2 (debond), T2-T3 (1 month post-treatment), and T3-T4 (6 months post-treatment) for longitudinal analysis

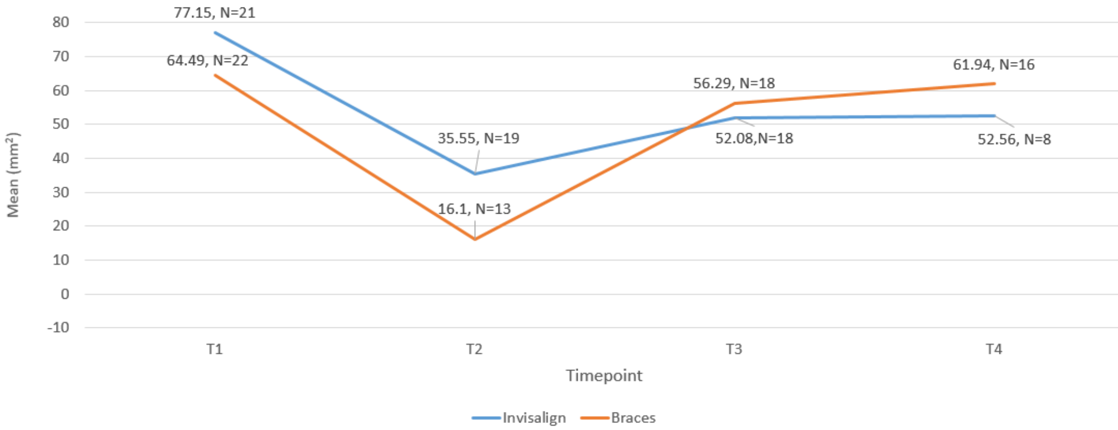

Figure 11A: Mean areas of near contact (51-350µ) at T1 (pre-treatment), T2 (debond), T3 (1 month post-treatment), and T4 (6 months post-treatment) for mixed-longitudinal analysis

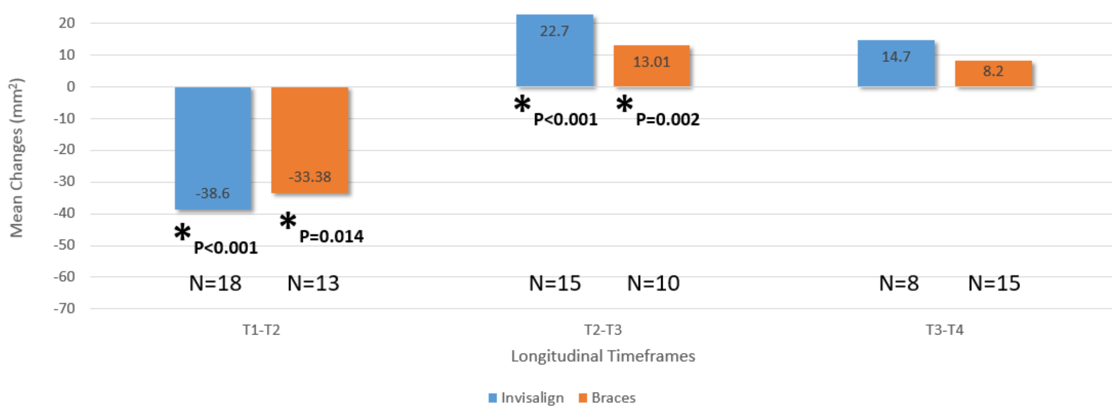

Figure 11B: Mean changes in areas of near contact (51-350µ) between T1 (pre-treatment) and T2 (debond), T2-T3 (1 month post-treatment), and T3-T4 (6 months post-treatment) for mixed-longitudinal analysis

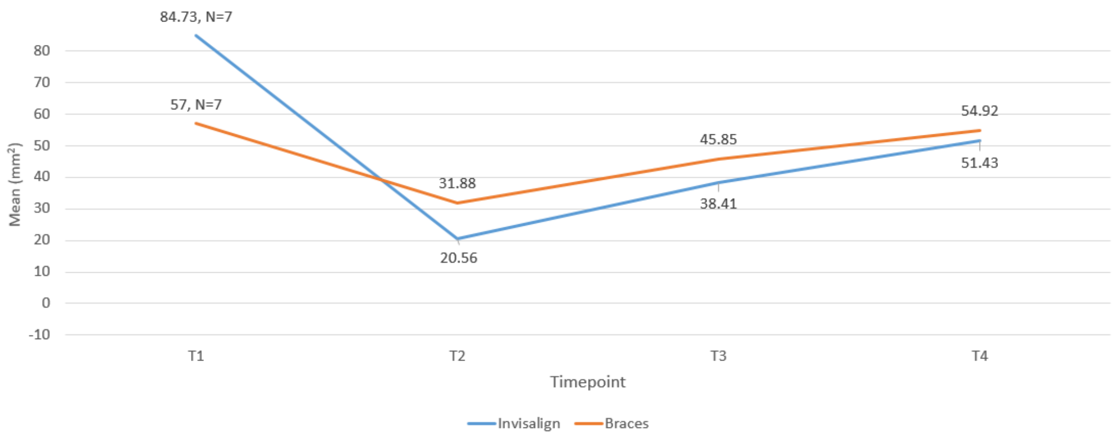

Figure 11C: Mean areas of near contact (51-350µ) at T1 (pre-treatment), T2 (debond), T3 (1 month post-treatment), and T4 (6 months post-treatment) for longitudinal analysis

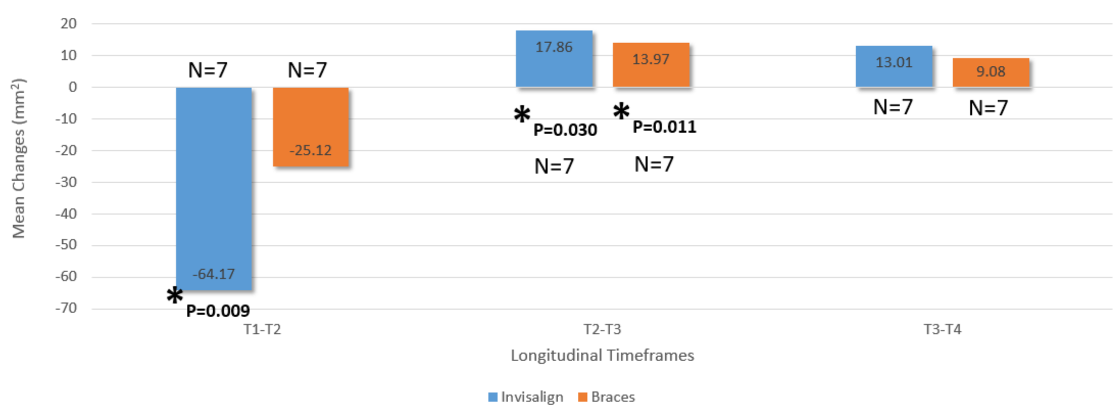

Figure 11D: Mean Changes in areas of near contact (51-350µ) between T1 (pre-treatment) and T2 (debond), T2-T3 (1 month post-treatment), and T3-T4 (6 months post-treatment) for longitudinal analysis

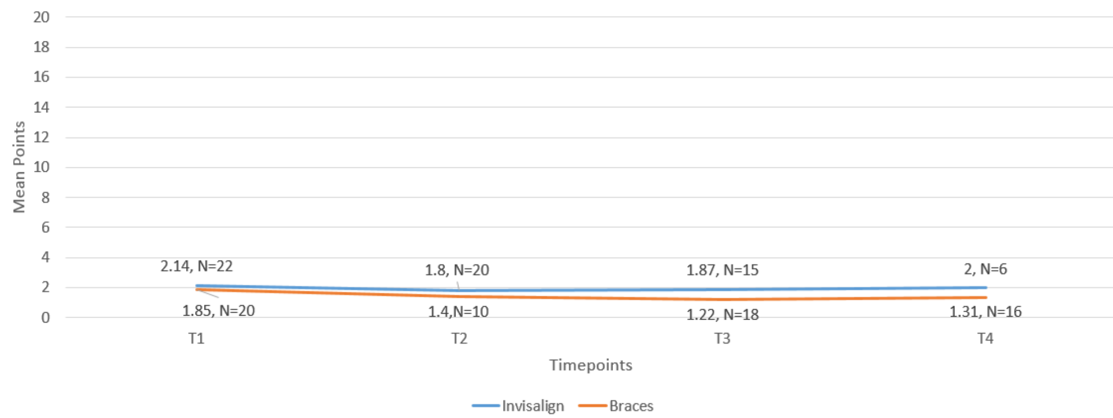

Figure 12A: Mean ABO OGS points for marginal ridges at T1 (pre-treatment), T2 (debond), T3 (1 month post-treatment), and T4 (6 months post-treatment) for mixed-longitudinal Analysis

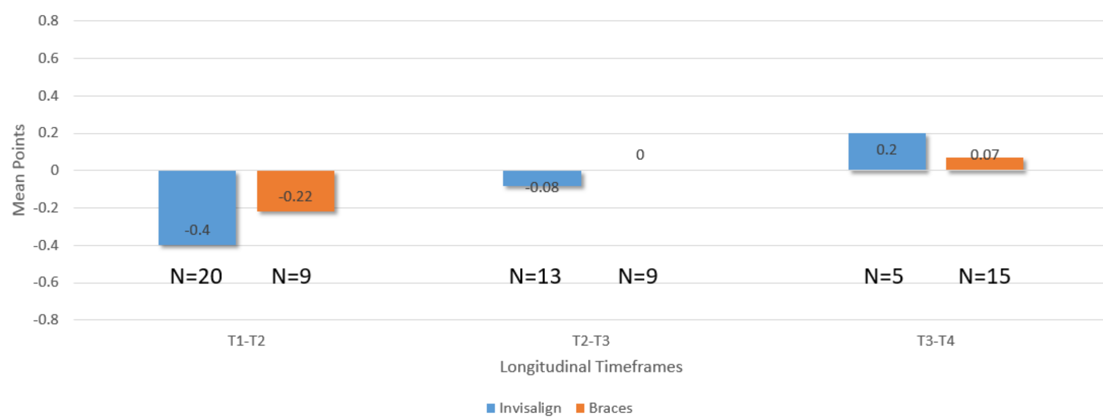

Figure 12B: Mean changes in ABO OGS points for marginal ridges between T1 (pre-treatment) and T2 (debond), T2-T3 (1 month post-treatment), and T3-T4 (6 months post-treatment) for mixed-longitudinal analysis

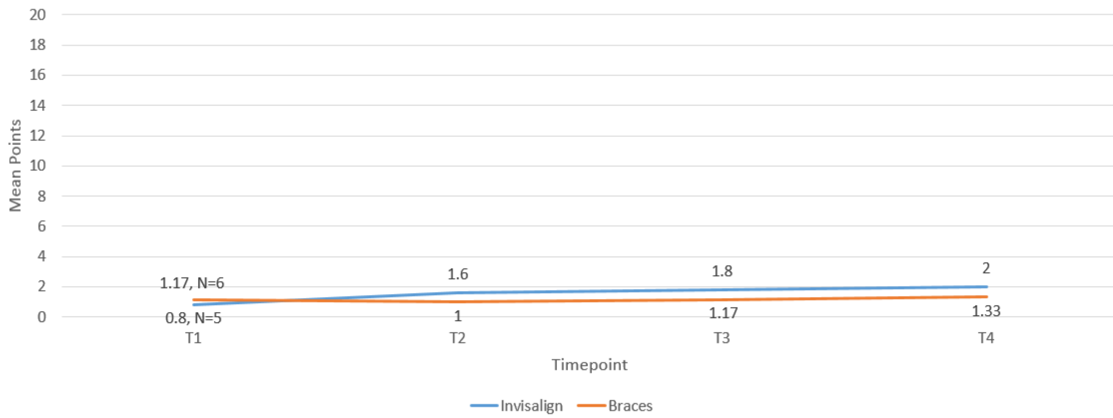

Figure 12C: Mean ABO OGS points for marginal ridges at T1 (pre-treatment), T2 (debond), T3 (1 month post-treatment), and T4 (6 months post-treatment) for longitudinal analysis

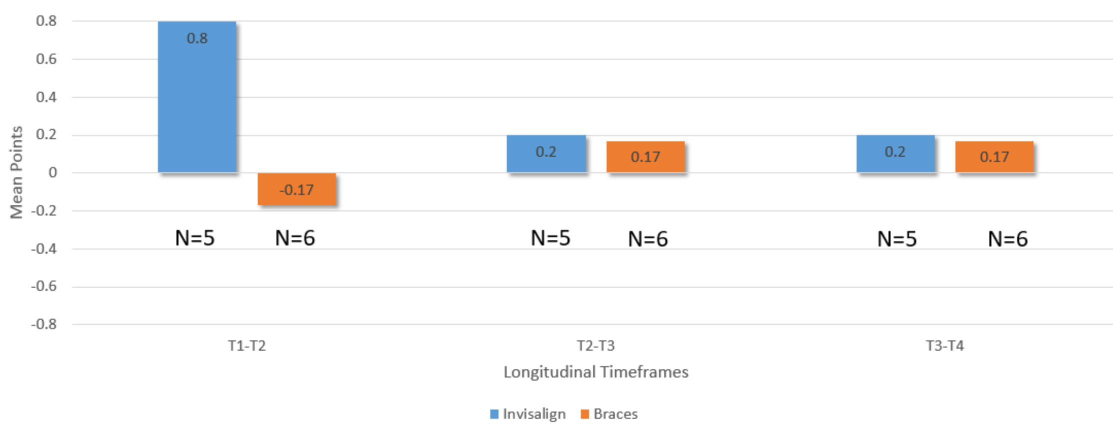

Figure 12D: Mean changes in ABO OGS points for marginal ridges between T1 (pre-treatment) and T2 (debond), T2-T3 (1 month post-treatment), and T3-T4 (6 months post-treatment) for longitudinal analysis

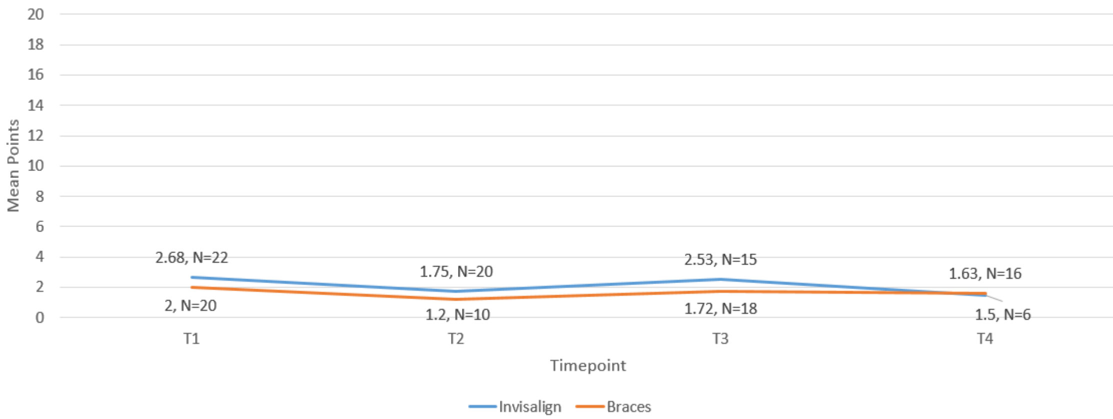

Figure 13A: Mean ABO OGS points for buccolingual inclination at T1 (pre-treatment), T2 (debond), T3 (1 month post-treatment), and T4 (6 months post-treatment) for mixed-longitudinal analysis

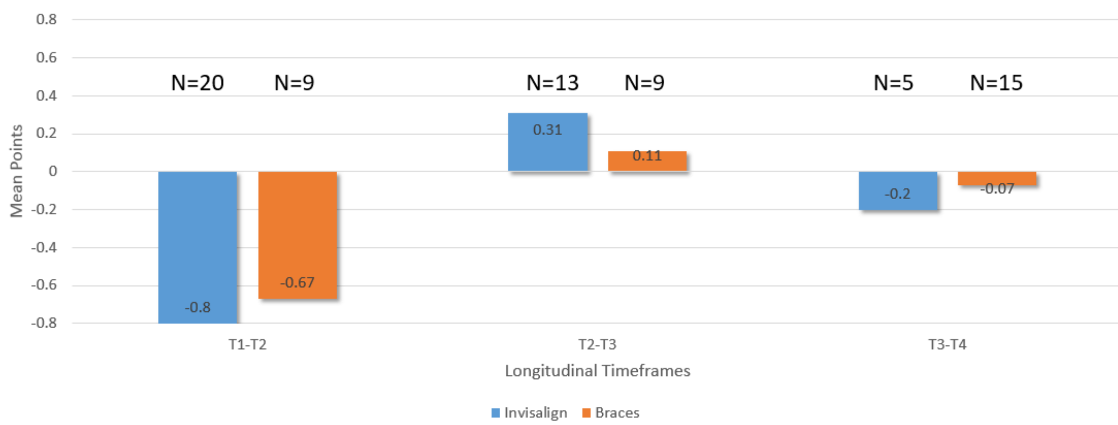

Figure 13B: Mean changes in ABO OGS points for buccolingual inclination between T1 (pre-treatment) and T2 (debond), T2-T3 (1 month post-treatment), and T3-T4 (6 months post-treatment) for mixed-longitudinal analysis

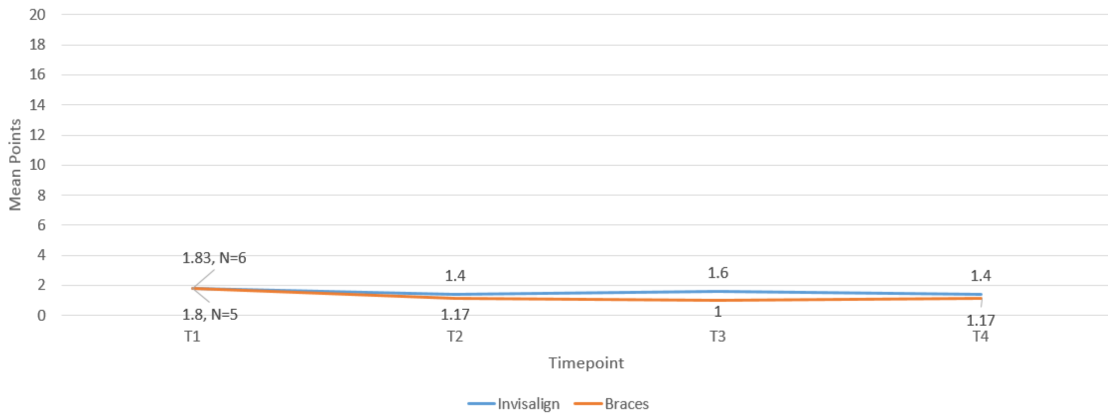

Figure 13C: Mean ABO OGS points for buccolingual inclination at T1 (pre-treatment), T2 (debond), T3 (1 month post-treatment), and T4 (6 months post-treatment) for longitudinal analysis

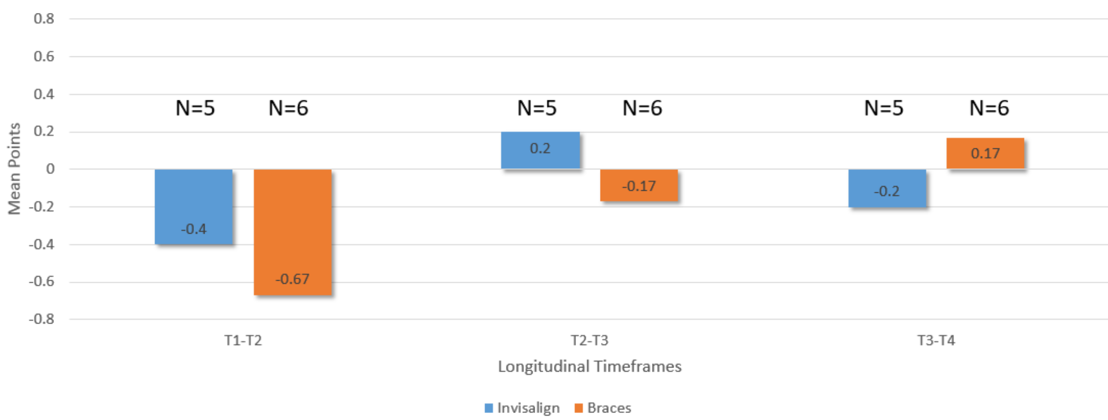

Figure 13D: Mean changes in ABO OGS points for buccolingual inclination between T1 (pre-treatment) and T2 (debond), T2-T3 (1 month post-treatment), and T3-T4 (6 months post-treatment) for longitudinal analysis

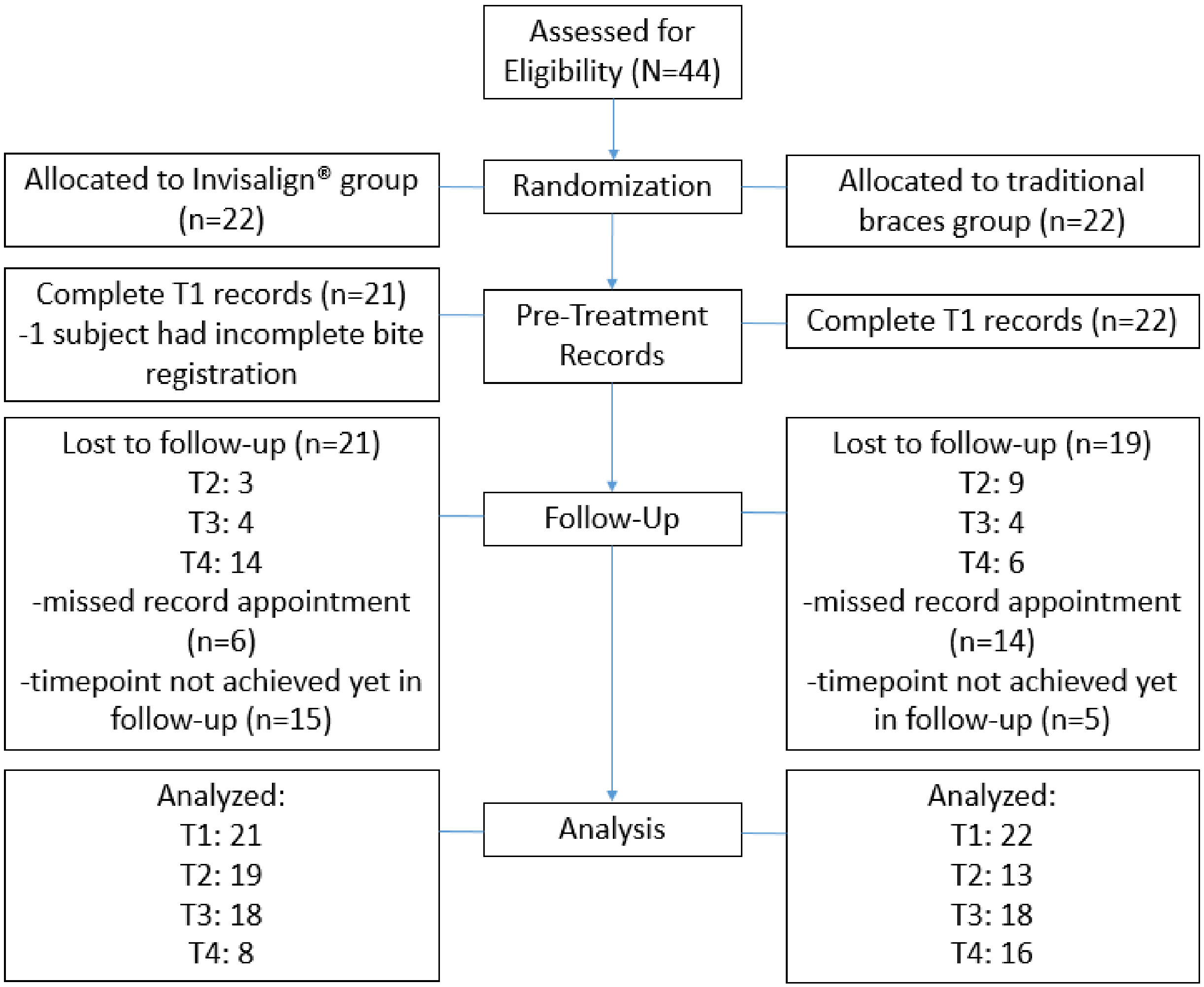

Figure 14: Patient flowchart

APPENDIX B TABLES

Author	Method	Pass Rate	Mean Scores					
			Occlusal Contacts		**Occlusal Relationships**		**Marginal Ridges**	
			Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
Kassas et al[3]	ABO MGS	INV: 1/31**	5.48	6.71	9.26	10.26	2.58	2.00
Li et al[2]	ABO OGS	INV: 67%	6.13	4.25	6.31	4.35	4.56	1.81
		BRA: 75%	7.22 **	3.32**	6.37**	3.40**	5.35**	1.56**
			INV	**Braces**	**INV**	**Braces**	**INV**	**Braces**
Djeu et al[4]	ABO OGS	INV: 21% BRA: 48%**	10.46 **	5.65 **	7.71 **	5.50 **	4.90	4.44
			ClinCheck®	**Actual**	**ClinCheck®**	**Actual**	**ClinCheck®**	**Actual**
Buschang et al[62]	ABO OGS	N/A	2.0 **	3.0 **	2.0 **	4.0 **	2.0 **	3.0 **

Table 1: Summary of mean ABO OGS points lost (** denotes significance, $p<0.05$)

Retainer Type	Author	Result	Significant?
Hawley	Hoybjerg et al[32]	ABO occlusal contact score improved from 5.47 to 3.33	Y
	Horton et al[10]	ACNC improved 6.71 mm^2 to 10.97 mm^2	Y
	Bauer et al[9]	ACNC improved 7.01 mm^2 to 16 mm^2	Y
Wraparound	Basciftci et al[73]	# of posterior contacts increased from 13.93 to 17.09	Y
Positioners	Bauer et al[9]	ACNC improved 8.3 mm^2 to 13.2 mm^2	Y
	Horton et al[10]	ACNC improved 8.44 mm^2 to 13.95^2	Y
Essix	Sauget et al[13]	# of posterior contacts increased from 23.67 to 27.93	N
	Aslan et al[75]	Full coverage: 22.33 to 24.77 Modified coverage: 22.38 to 25.72	N Y

Table 2: Evaluation of occlusal contact changes based on retainer type

Microns	**Step Wedge #1** *(400 pixels)*	**Step Wedge #2** *(402 pixels)*	**Step Wedge #3** *(403 pixels)*	**Average Grayscale/Byte Values**
50	196	202	196	198
100	163	167	158	163
150	134	134	124	131
200	111	104	99	105
250	80	84	76	80
300	66	65	59	63
350	49	52	50	50

Table 3: Three step wedges and their corresponding byte values per 50 micron increment

	Micron Thickness Range	**Grayscale Byte Range**
Absolute Contact	0-50	255-198
Near Contact	51-100	197-163
	101-150	162-131
	151-200	130-105
	201-250	104-80
	251-300	79-63
	301-350	62-50
No contact	≥351	49-0

Table 4: Grayscale ranges for ACNC derived from the average byte values of the three steps wedges

	Invisalign			*Braces*			
	N	**Mean**	**Standard Deviation**	**N**	**Mean**	**Standard Deviation**	**Probability Difference**
T1-T2	21	1.97	0.42	21	1.41	0.39	<0.001
T2-T3	16	0.15	0.07	17	0.09	0.04	0.007
T3-T4	7	0.36	0.10	14	0.46	0.11	0.058
T2-T4	7	0.51	0.05	16	0.55	0.10	0.328

Table 5: Mean time elapsed (years) between T1 (pre-treatment), T2 (debond), T3 (1 month post-treatment), and T4 (6 months post-treatment) in groups

APPENDIX C EQUATIONS

$$\frac{400 + 402 + 403}{3} = 401.67 \text{ pixels}$$

$$\frac{10\ mm}{(Average\ \#\ of\ pixels\ in\ 10\ mm)} = \frac{X\ mm}{1\ pixel}$$

$$\frac{10\ mm}{401.67 \text{ pixels}} = \frac{\text{X mm}}{\text{pixel}}$$

$$= 0.0249\ mm\ length\ of\ a\ pixel$$

$$area\ of\ one\ pixel = 0.00062\ mm^2$$

Equation 1: Calculating the area of a pixel

50 microns:

$$(x - h)^2 + (y - k)^2 = r^2$$

$$(x - 0)^2 + (y - 19.05\ mm)^2 = 19.05^2$$

$$x^2 + (0.05\ mm - 19.05\ mm)^2 = 362.90\ mm^2$$

$$x^2 + (-19.0\ mm)^2 = 362.90\ mm^2$$

$$x^2 + 361\ mm^2 = 362.90\ mm^2$$

$$x^2 = 1.90\ mm^2$$

$$x = 1.379\ mm$$

$$x = 1.379\ mm\ from\ sphere's\ center\ is\ 50\ microns\ thick$$

350 microns:

$$(x - h)^2 + (y - k)^2 = r^2$$

$$(x - 0)^2 + (y - 19.05\ mm)^2 = 19.05^2$$

$$x^2 + (0.35\ mm - 19.05\ mm)^2 = 362.9025\ mm^2$$

$$x^2 + (-18.7\ mm)^2 = 362.9025\ mm^2$$

$$x^2 + 349.69\ mm^2 = 362.9025\ mm^2$$

$$x^2 = 13.2125\ mm^2$$

$$x = 3.635\ mm$$

$$x = 3.635\ mm\ from\ sphere's\ center\ is\ 350\ microns\ thick$$

Equation 2: Step wedge calculations based on circle equation

50 microns:

$$\frac{\#\,pixels}{10\ mm} = \frac{X\ pixels}{Thickness(mm) at\ micron\ distance\ from\ (0,0)}$$

$$\frac{400\ pixels}{10\ mm} = \frac{X\ pixels}{1.379\ mm}$$

$$10x = 551.6$$

$$x = pixels\ 1 - 55\ are\ absolute\ contact$$

350 microns:

$$\frac{400\ pixels}{10\ mm} = \frac{X\ pixels}{3.635\ mm}$$

$$10x = 1454$$

$$x = pixels\ \#56 - 145\ are\ near\ contact$$

Equation 3: Determining pixel value for ACNC